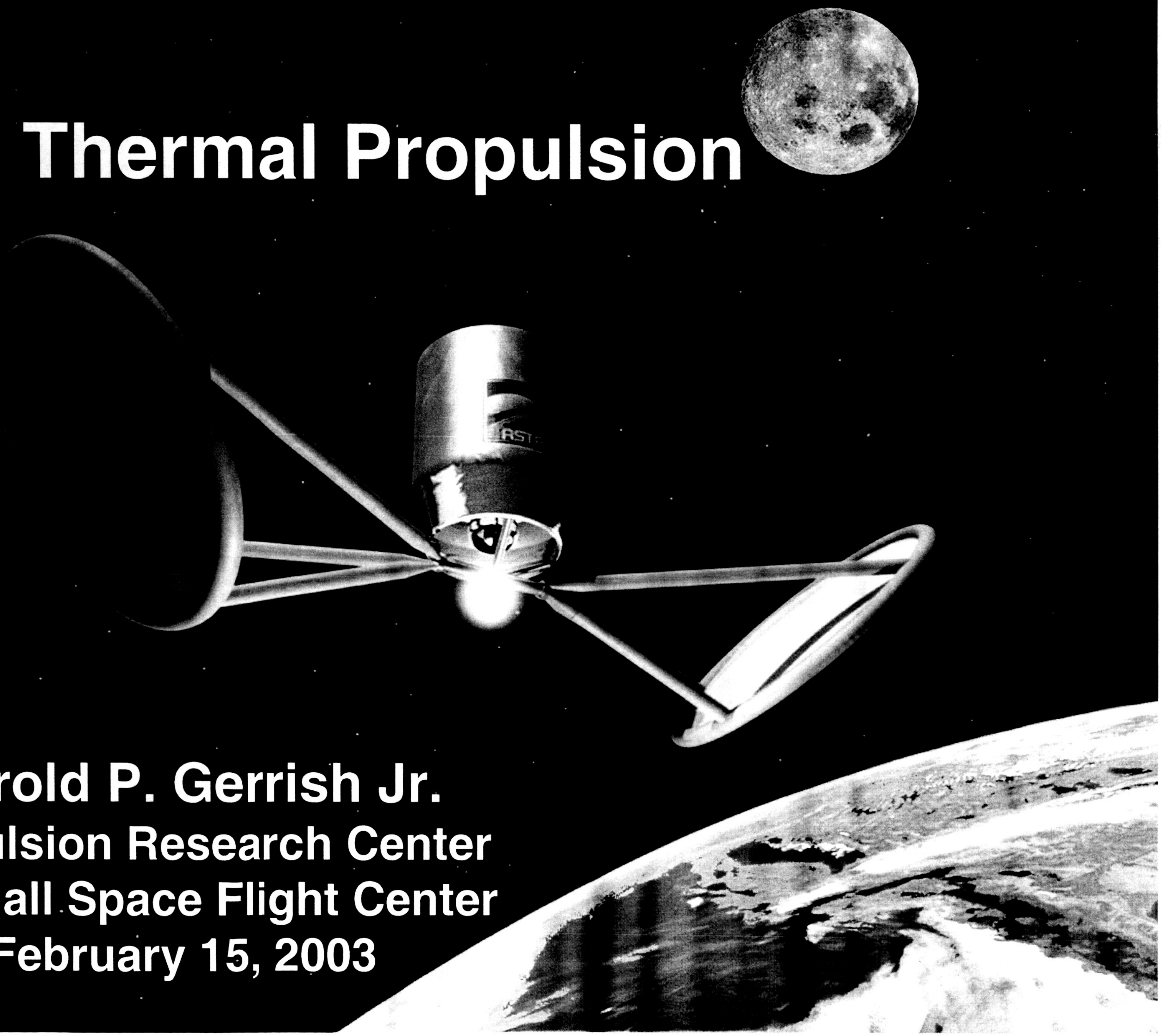
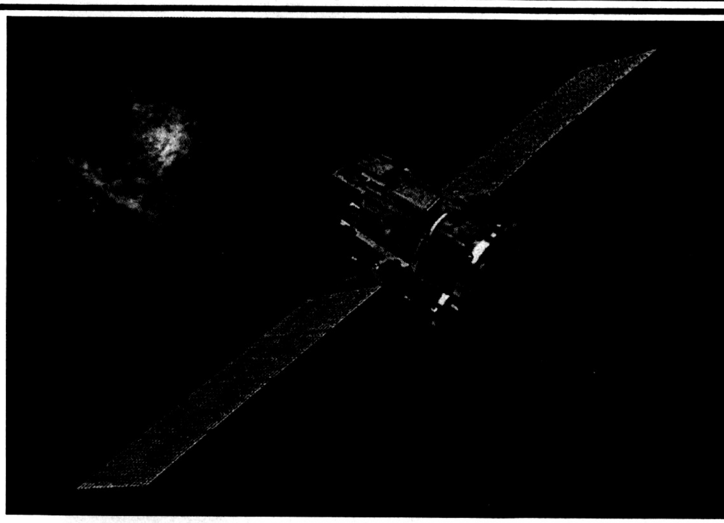
Solar Thermal Propulsion



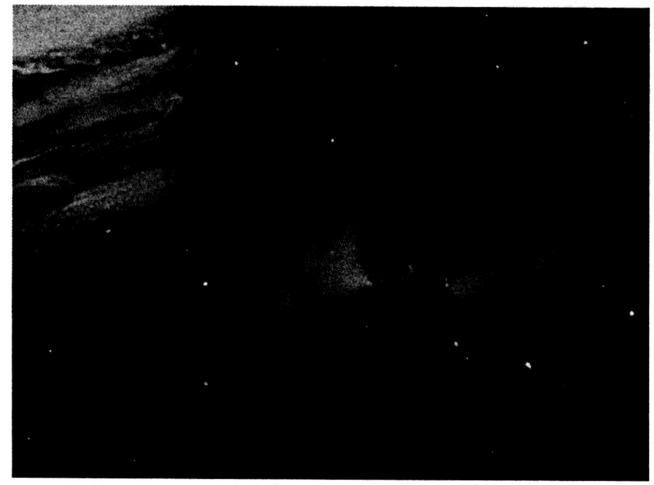
Harold P. Gerrish Jr.
Propulsion Research Center
Marshall Space Flight Center
February 15, 2003

WAYS TO USE SOLAR ENERGY FOR PROPULSION

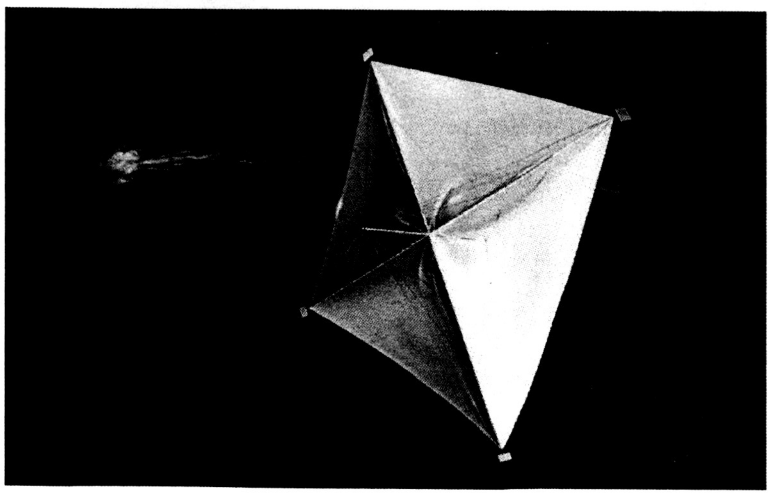
Propulsion Research Center



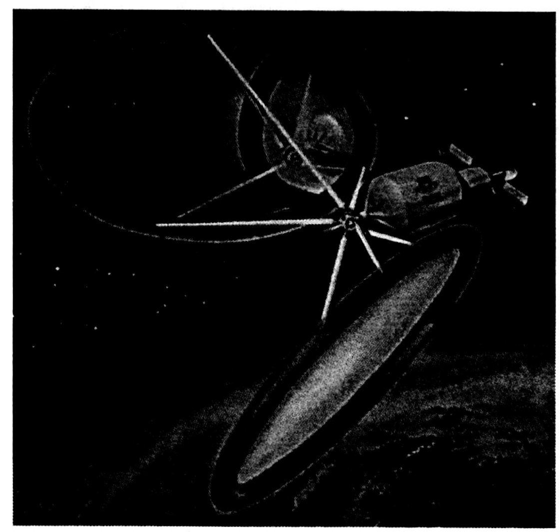
Solar Electric Propulsion



Plasma Sails-Solar Wind



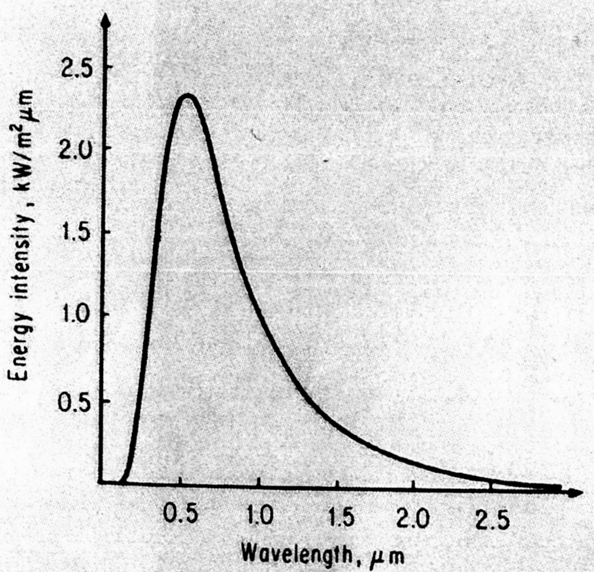
Solar Sails-Photon Momentum



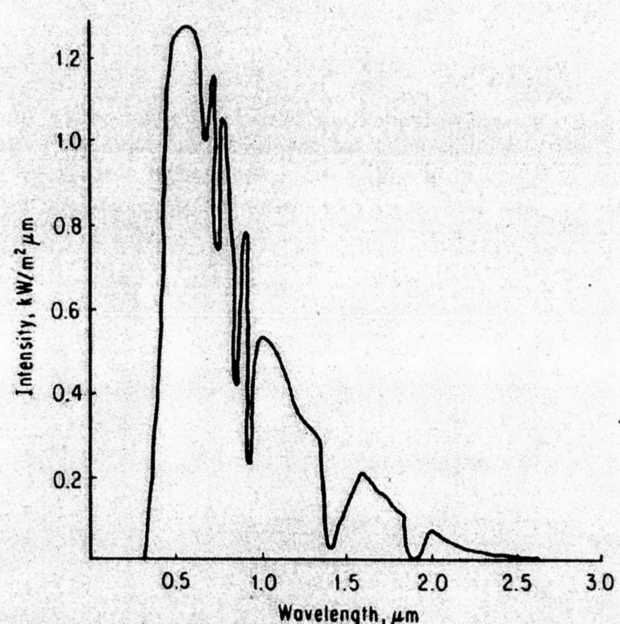
Solar Thermal Propulsion

SOLAR (FUSION) ENERGY

Propulsion Research Center



Spectral distribution of extraterrestrial solar radiation.



Approximate spectral distribution of solar radiation on earth with an air mass 2 atm.

- Solar Flux Intensity at Low Earth Orbit ~ 1400 W/m^2
- Solar Flux Intensity at Mars ~ 619 W/m^2
- Solar Flux Intensity at Huntsville, AL ~ 1000 W/m^2

BACKGROUND

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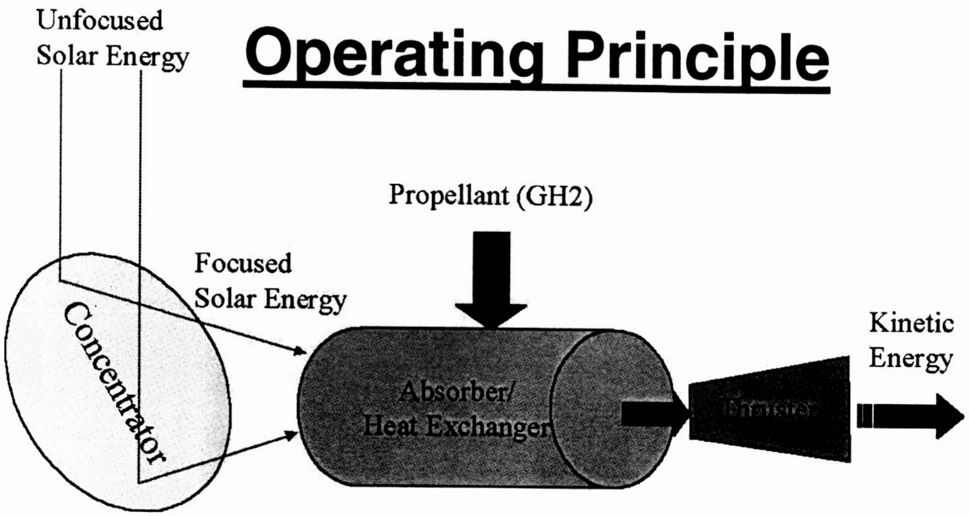
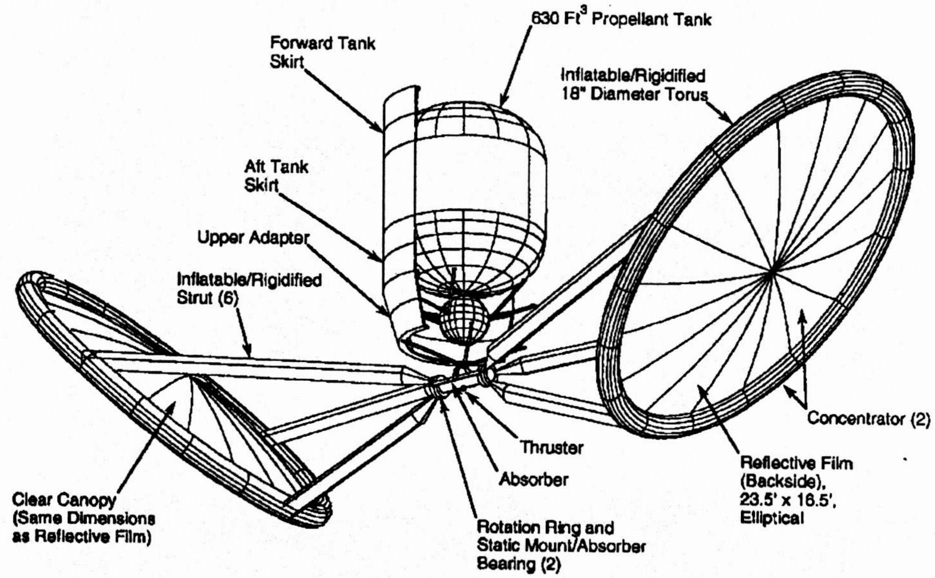
Operating Principle

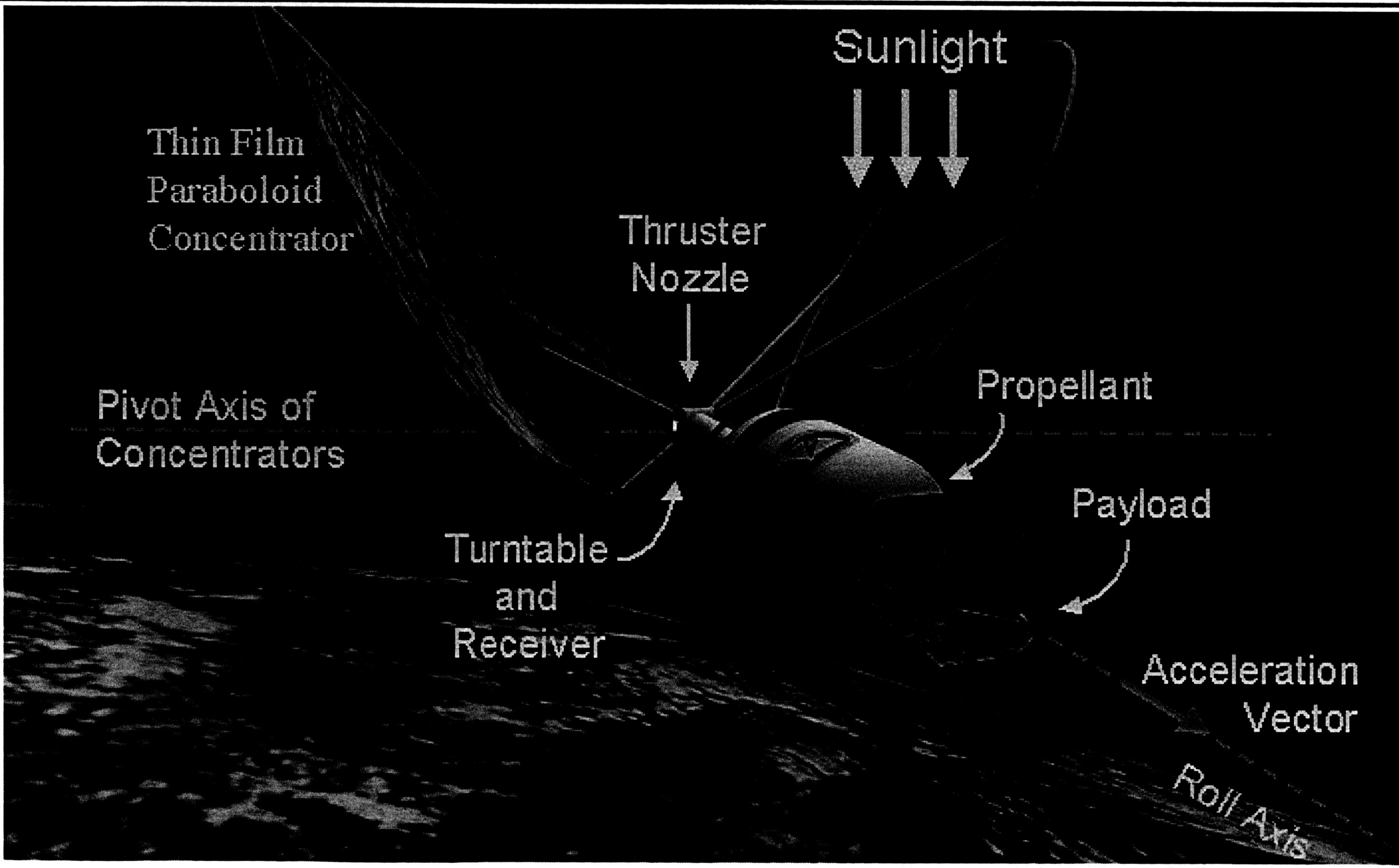




Solar Thermal Upper Stage

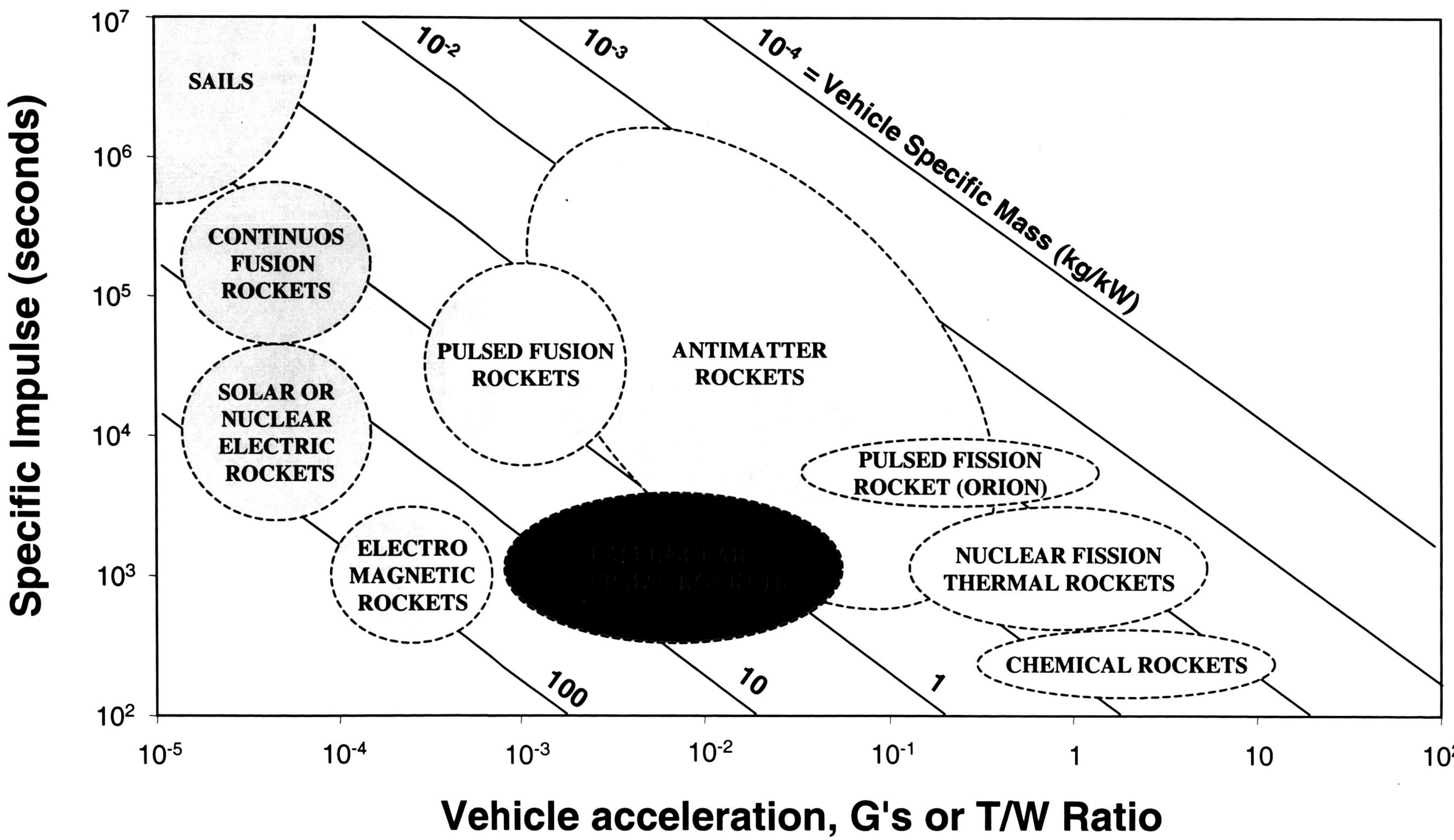
- 30-day orbit transfer of payload from low earth orbit to geosynchronous
- Allows greater payload mass in low earth orbit than traditional upperstages
- Future use as orbital maneuvering vehicle for satellites
- Design simplicity leads to lower development cost
- Technologies can be used with other propulsion concepts
- Primary concern is propellant volume required. Higher Isp reduces volume.

OPERATION IN ORBIT



PROPULSION CONCEPTS

Propulsion Research Center



CRITICAL EQUATIONS

Propulsion Research Center

Reaction Thrust = (propellant mass flow rate) x (exhaust velocity)

$$F = \dot{m} \times v_e$$

Specific Impulse = Thrust / (propellant weight flow rate)

$$Isp = \frac{F}{\left(\dot{m} \times g_c\right)} = \frac{v_e}{g_c}$$

$$Isp \propto \sqrt{\frac{T_o}{M}}$$

T_o is total exhaust temperature
M is average propellant molecular weight
g_c is gravitational constant

CRITICAL EQUATIONS

Propulsion Research Center

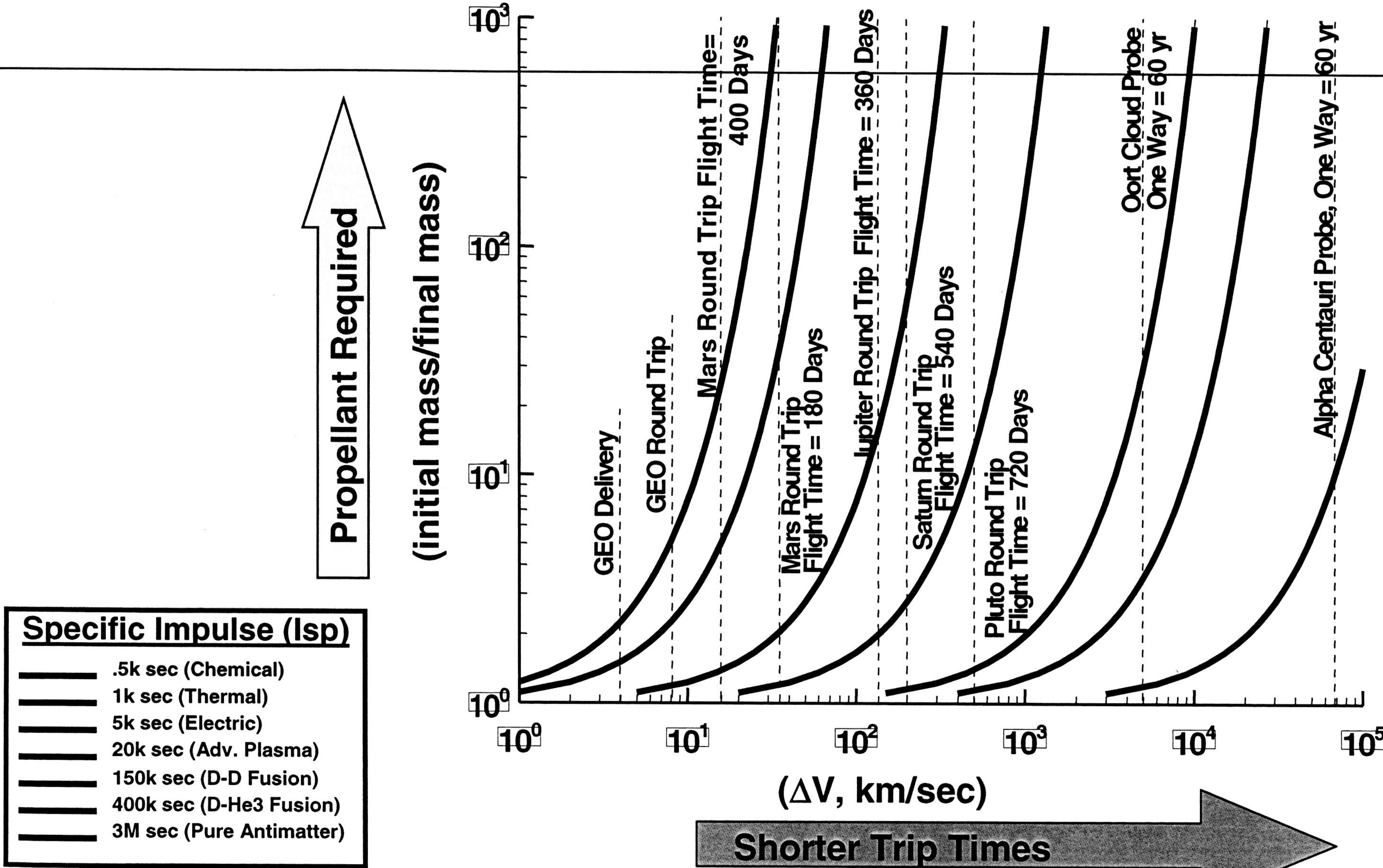
Spacecraft change in velocity (neglecting gravity loss)

$$\Delta V = Isp \times g_c \times \ln\left(\frac{m_i}{m_f}\right) \quad \text{and,} \quad m_p = m_i - m_f$$

m_i is initial vehicle mass including propellant
m_f is total vehicle mass after burn
m_p is propellant mass leaving the vehicle

Doubling the Isp decreases the propellant mass required ~60%, allowing added payload weight in the same launch vehicle ! However, some saved mass is lost to store greater propellant volume and account for low thrust gravity loss

Vehicle Momentum Transfer



$$\Delta V = Isp(g_c)\ln[m_i/m_f]$$

POWER EFFICIENCY

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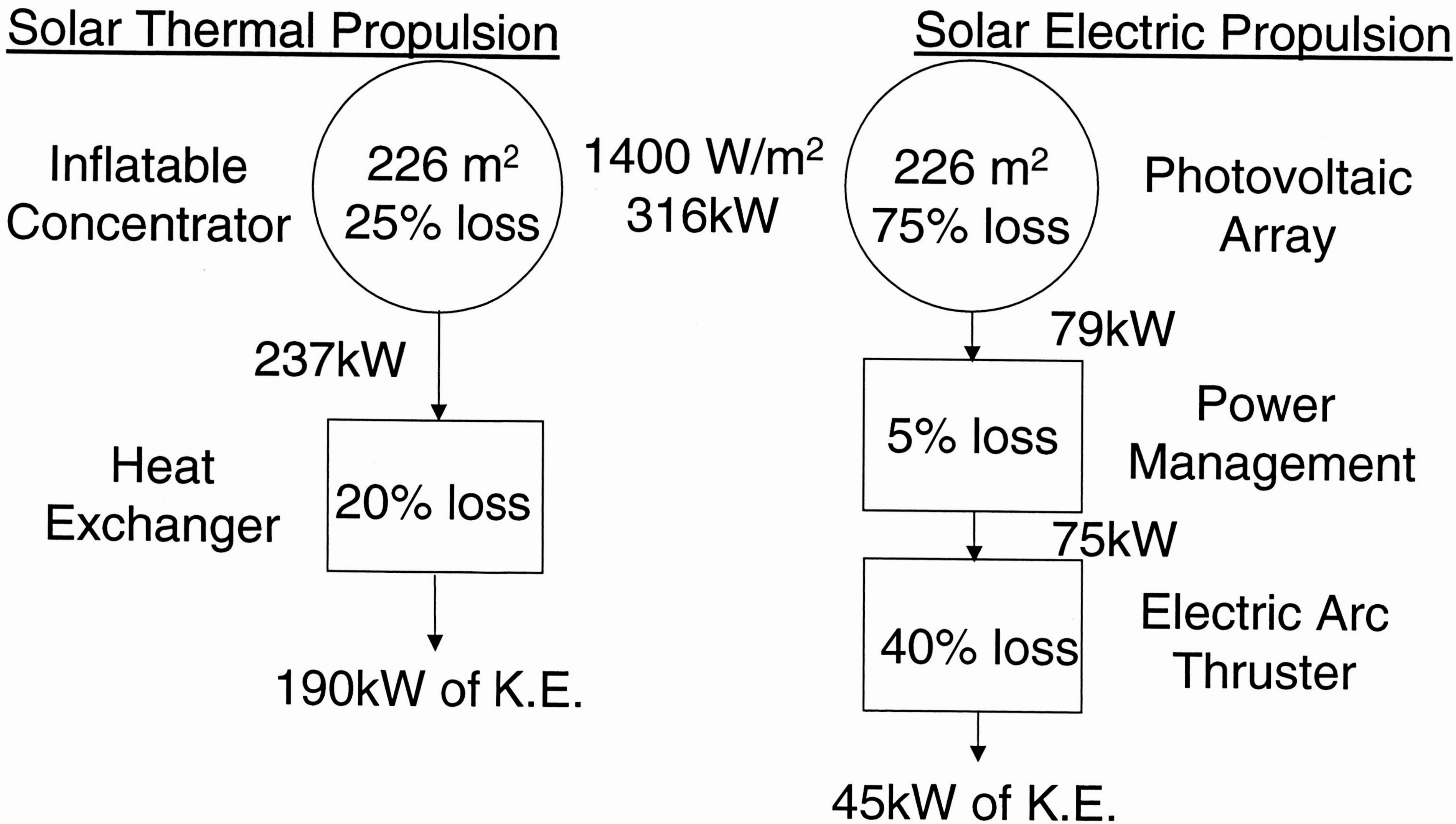
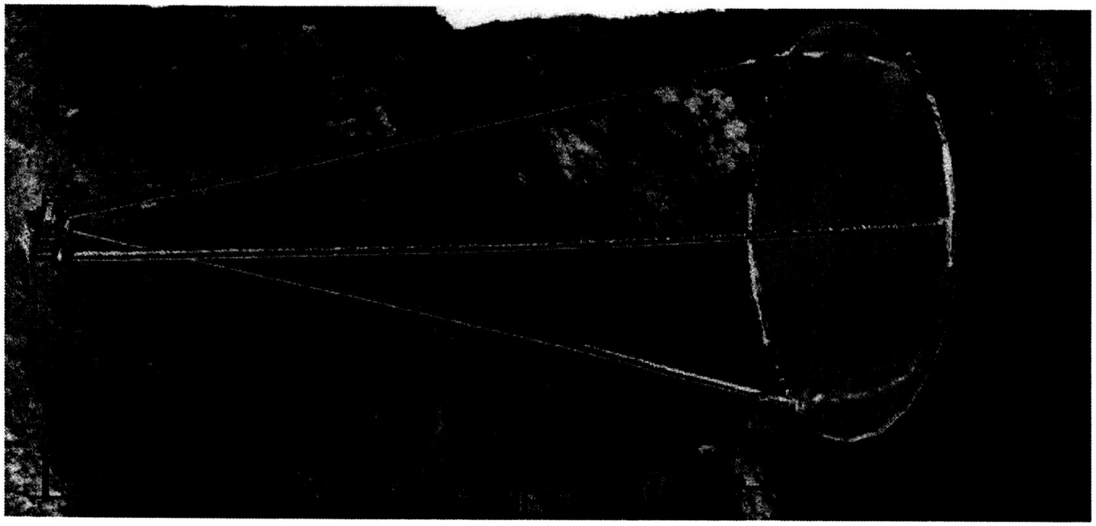


MAJOR STP PROJECTS

Propulsion Research Center

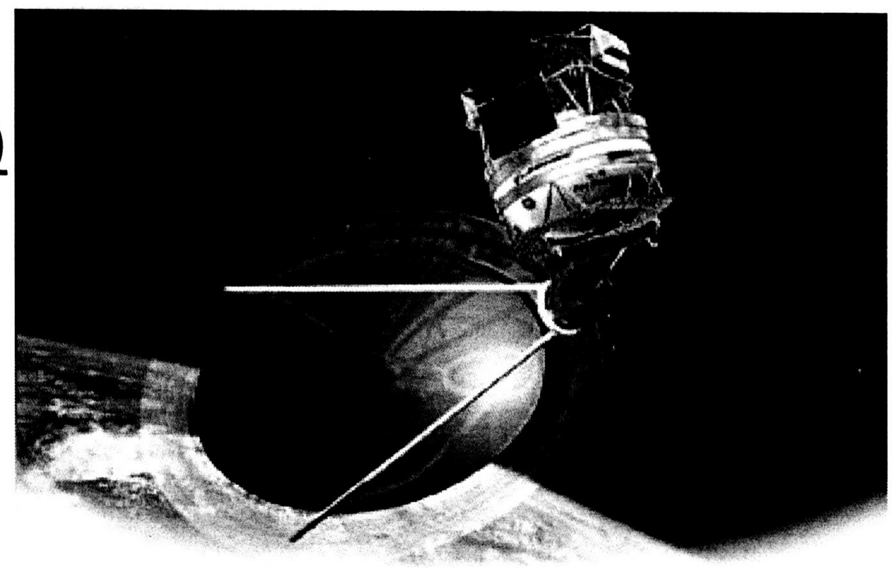


Past Programs

- Hercules
- Air Force-Rocketdyne
- MSFC-AITP-STUSTD
- MSFC-Shooting Star
- Air Force-IHPRPT
- Air Force-ISUS

Solar Orbit Transfer Vehicle (SOTV)

- Boeing
- SRS
- Thiokol
- Air Force Funded



TYPES OF STP ENGINES

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Direct Gain Engine

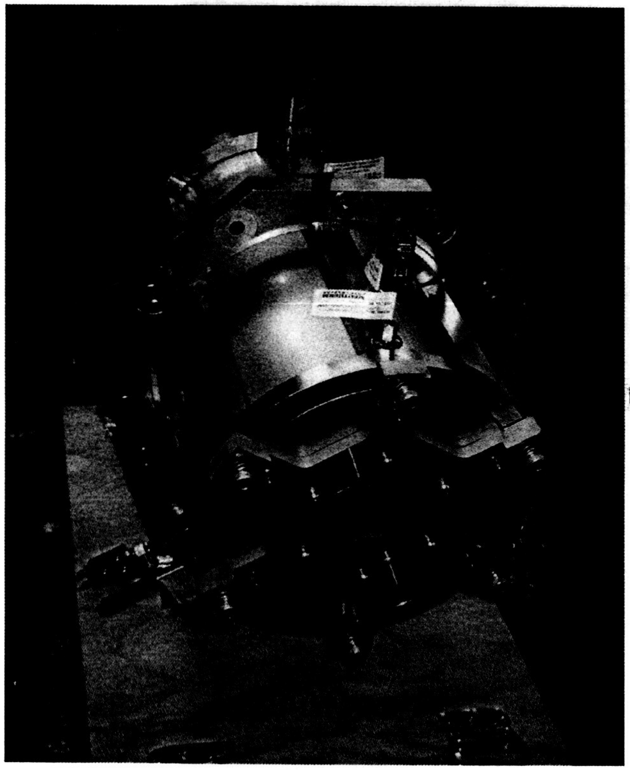
- Engine operates directly with focused sunlight
- Requires larger concentrators for more power
- Does not function in earth shadow
- Capable of very high temperatures and higher Isp with critical joints at low temperatures

Storage Engine

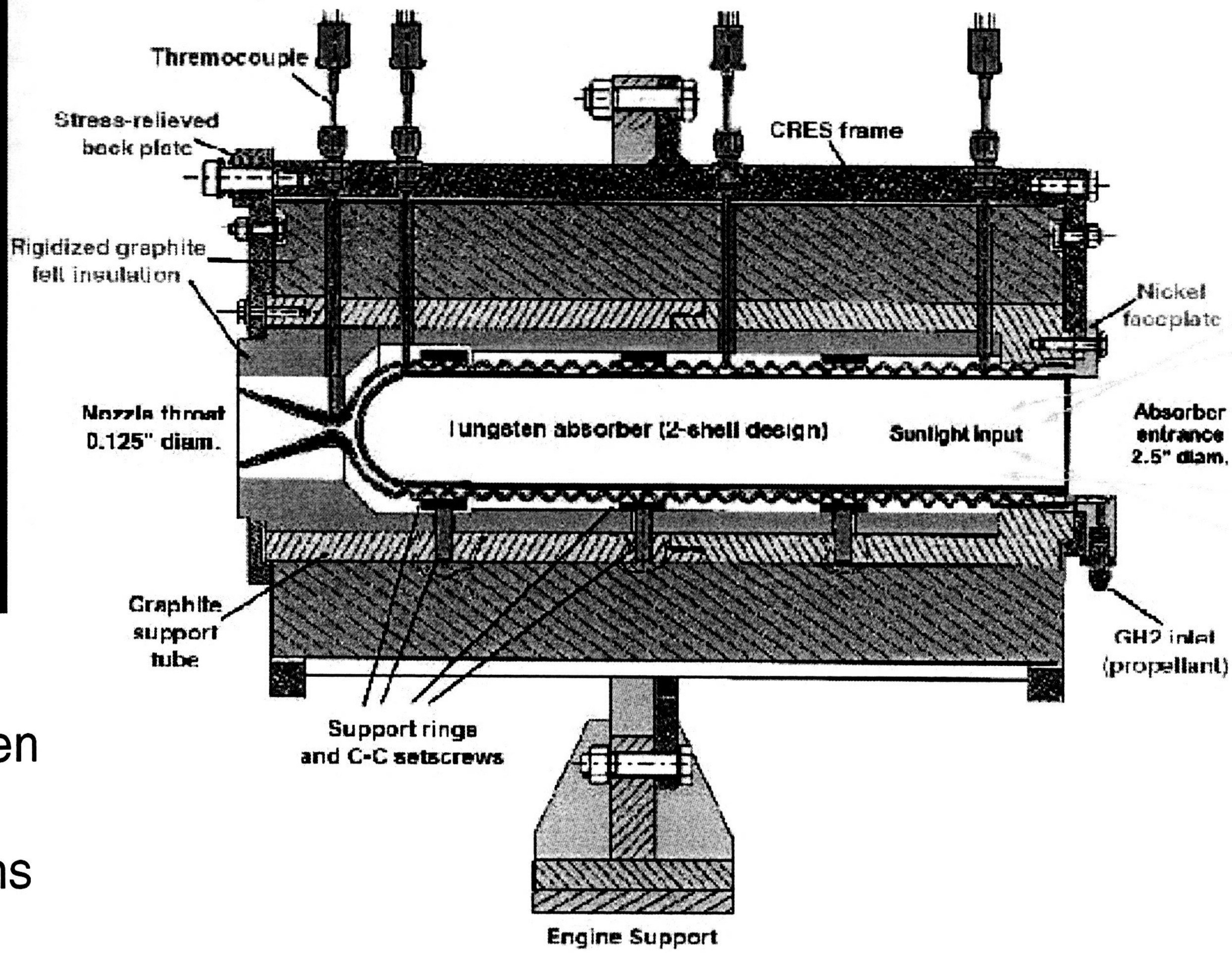
- Engine stores heat in reservoir for later propulsion use, even in shadow
- Smaller concentrator than direct gain
- Can shorten trip times with slightly greater thrust
- More reaction control system propellant required
- Lower Isp than direct gain due to temperature constraints

SOLAR THERMAL PROPULSION DIRECT GAIN ASSEMBLY

Propulsion Research Center



Solar Thermal Thruster STP-1



- .5 lbf thrust
- 2 lbs/hr flow rate hydrogen
- 10 kW solar power input
- Self cleaning of oxidations

SPECIFIC IMPULSE

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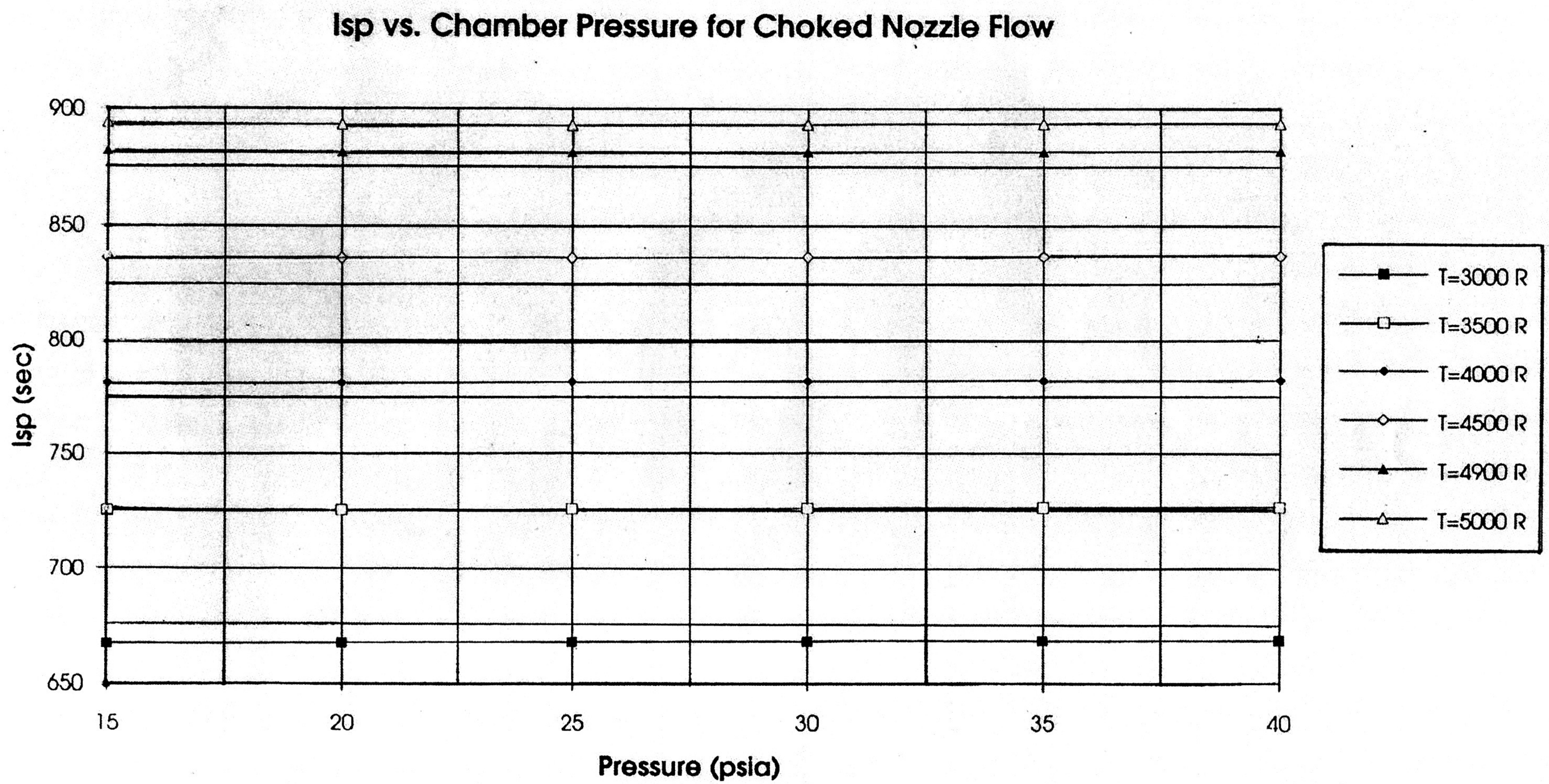
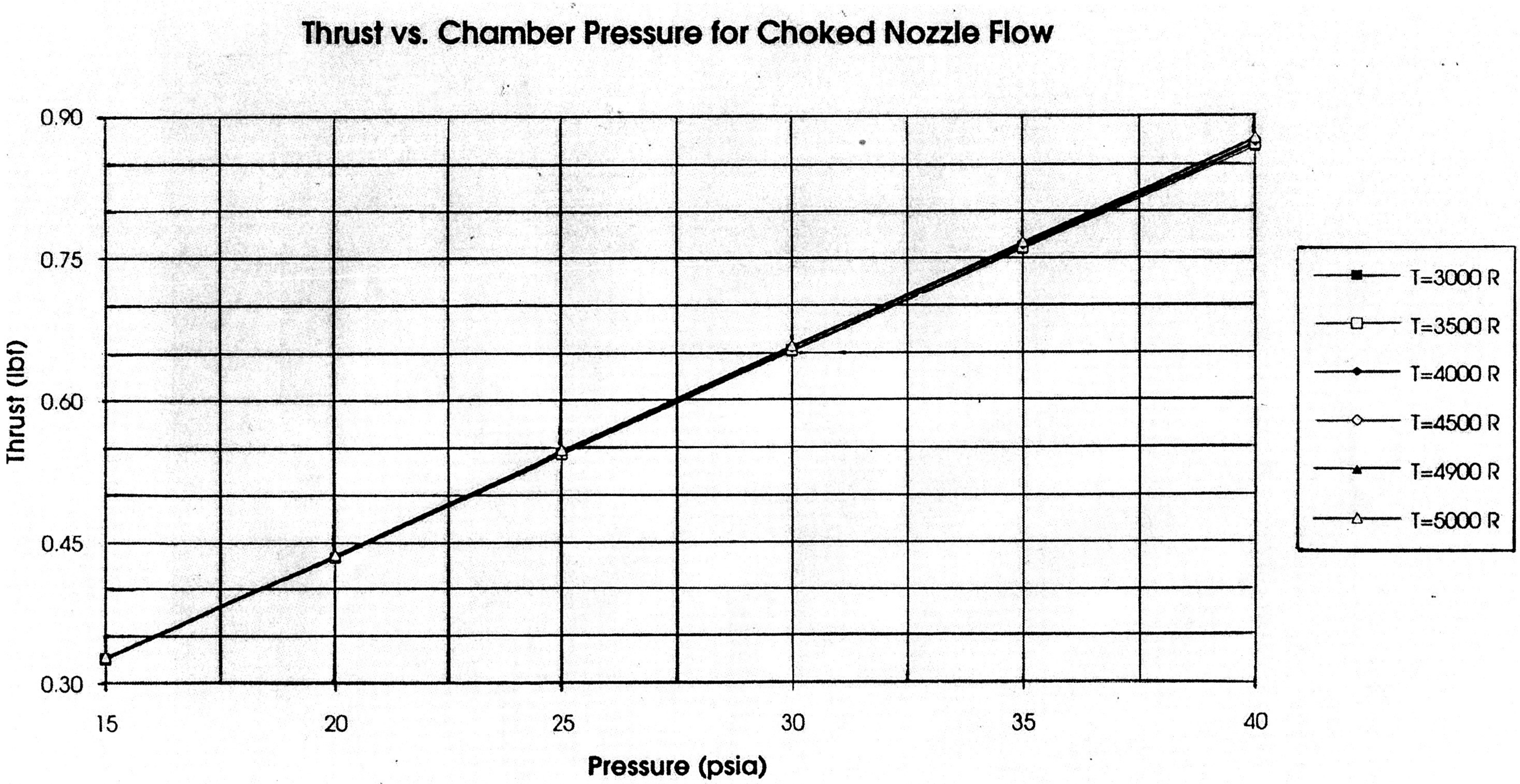


(Low inlet pressures are provided by pressure feed LH2 boil-off)

THRUST

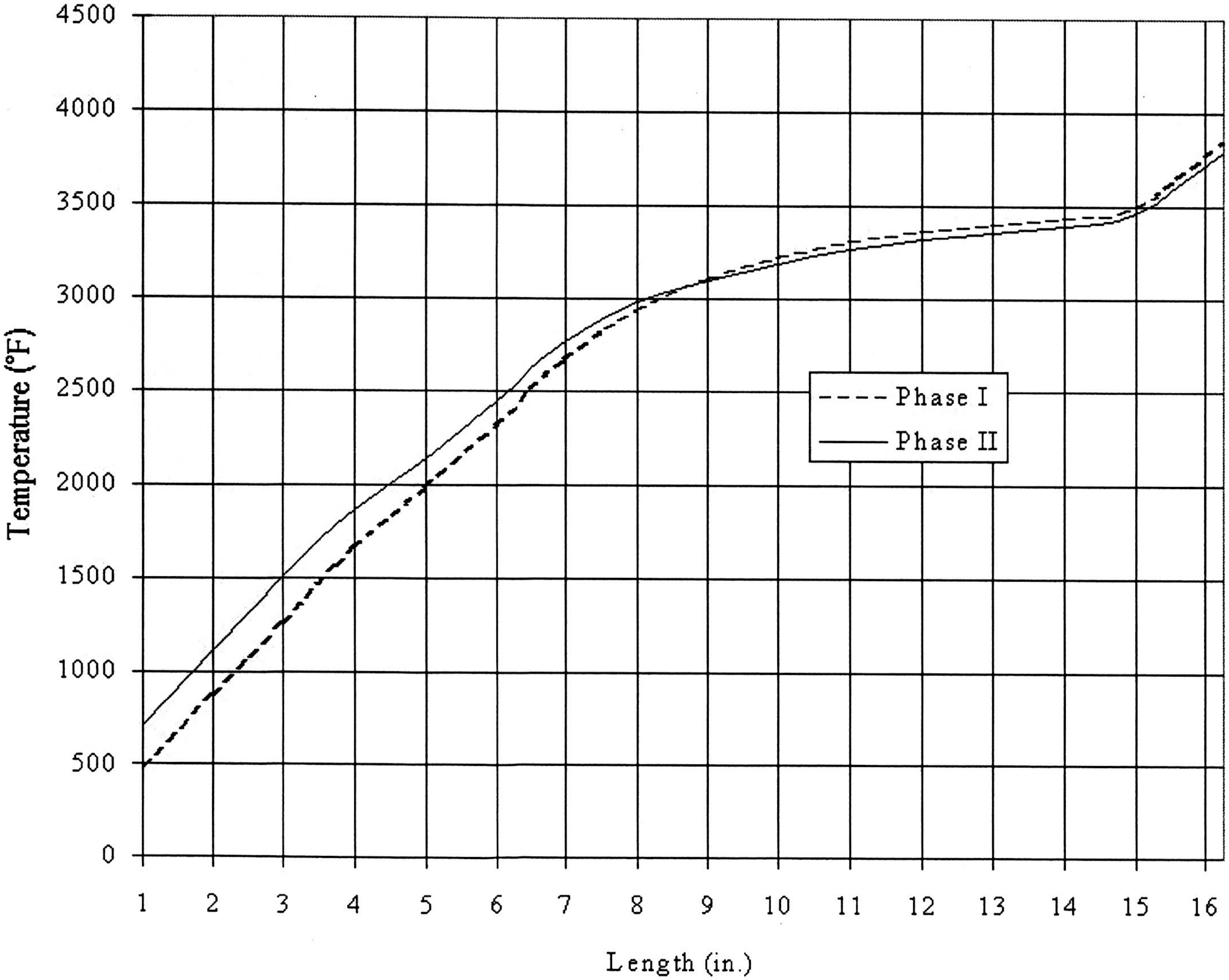
Propulsion Research Center



(Low inlet pressures are provided by pressure feed LH2 boil-off)

TEMPERATURE DISTRIBUTION

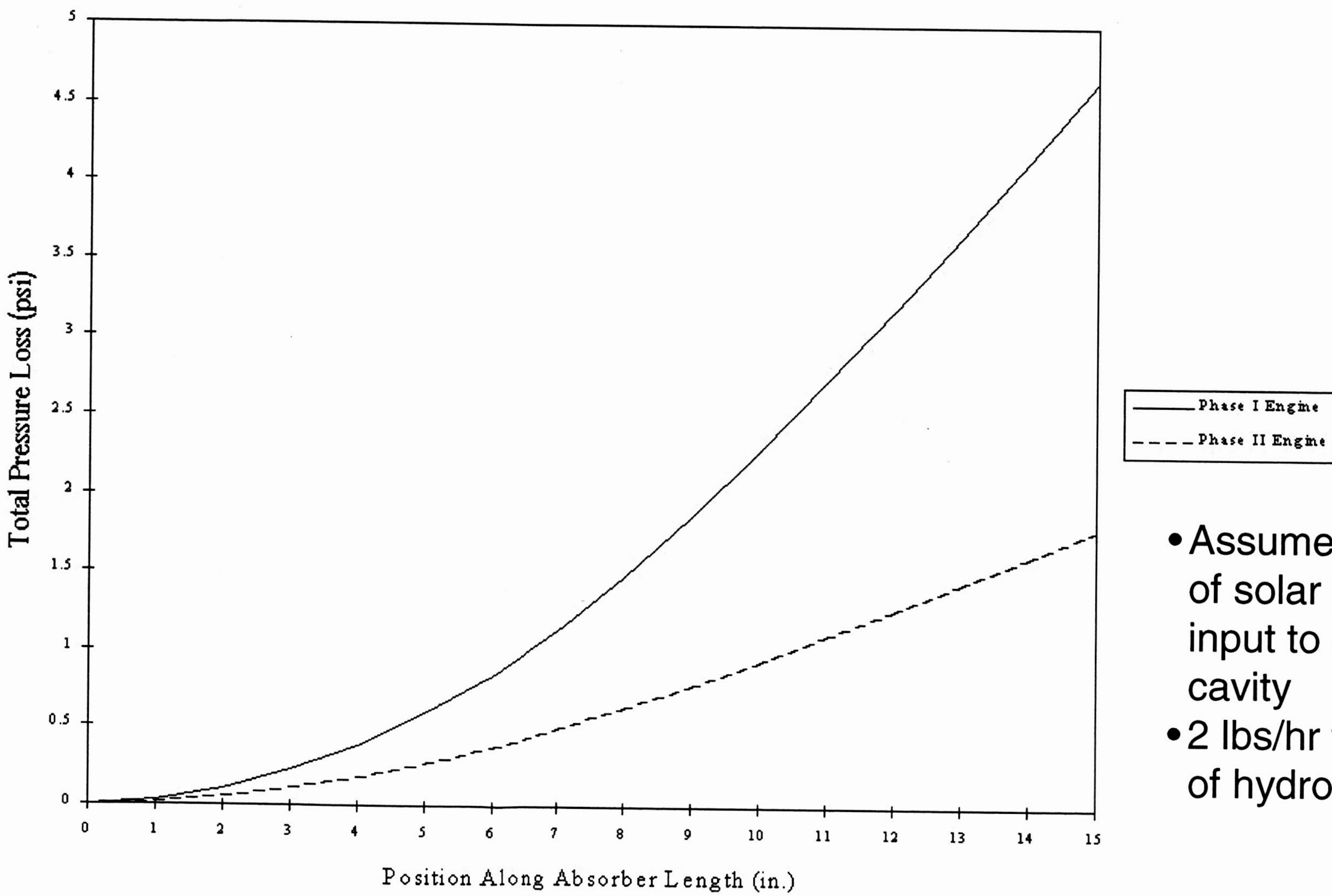
Propulsion Research Center



- Assumes 10 kW of solar power input to absorber cavity
- 2 lbs/hr flow rate of hydrogen

PRESSURE LOSS

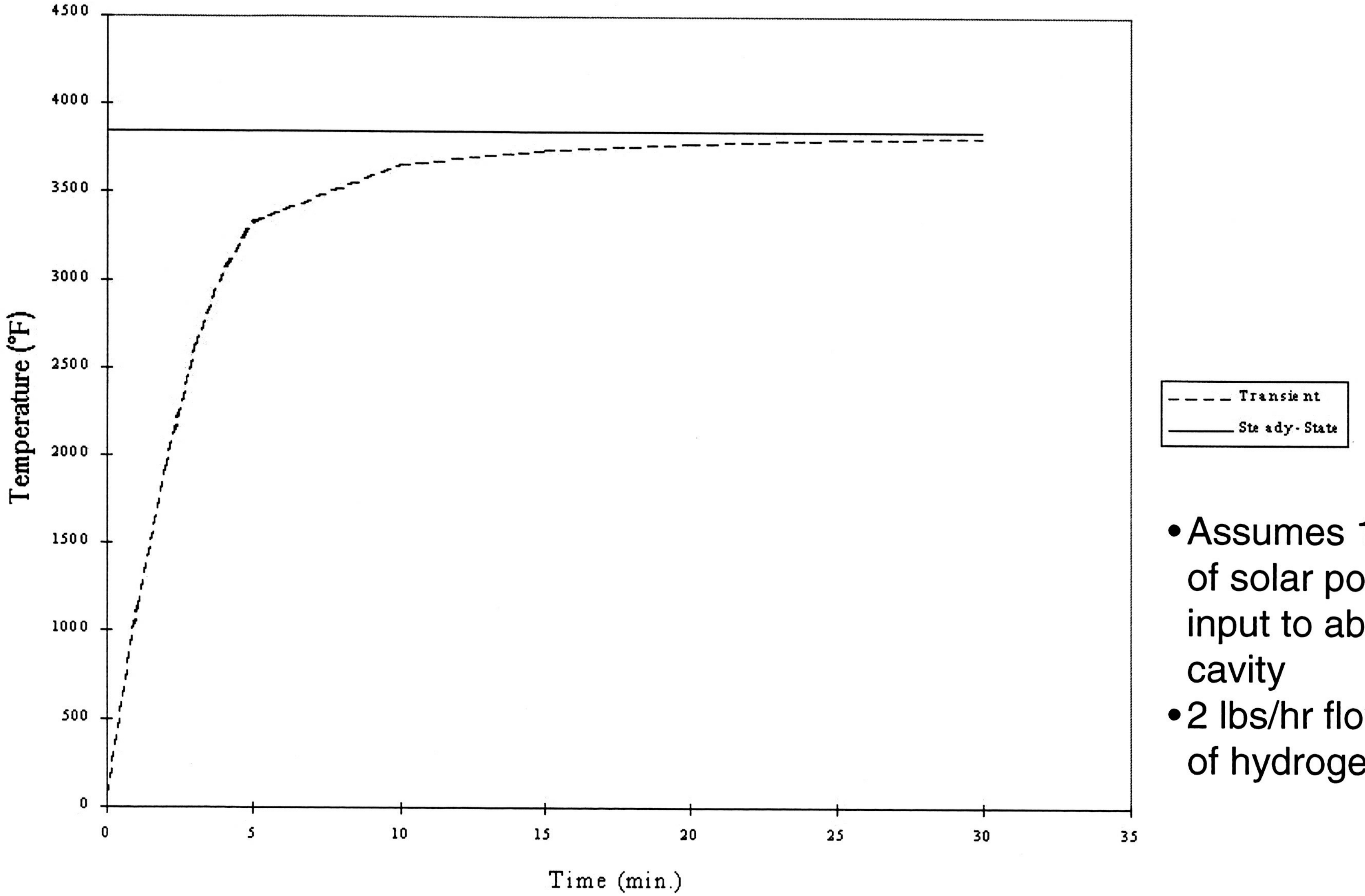
Propulsion Research Center



- Assumes 10 kW of solar power input to absorber cavity
- 2 lbs/hr flow rate of hydrogen

TRANSIENT STARTUP

Propulsion Research Center



- Assumes 10 kW of solar power input to absorber cavity
- 2 lbs/hr flow rate of hydrogen

AXIAL HEAT INPUT

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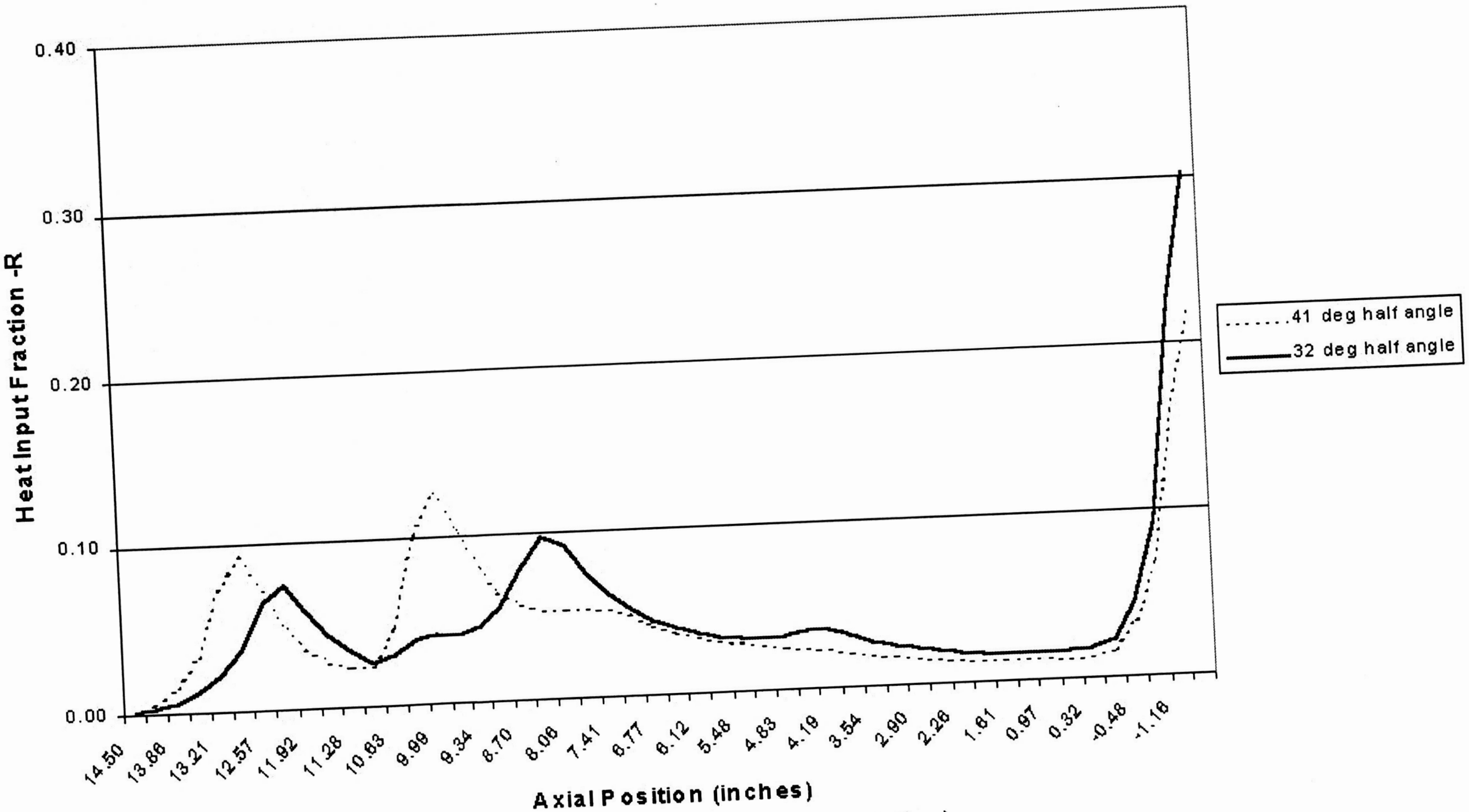
Normalized Heat Input Inside Absorber Cavity



(note: 14.5" is at cylindrical opening of absorber)

DIRECT GAIN ENGINE DESIGN

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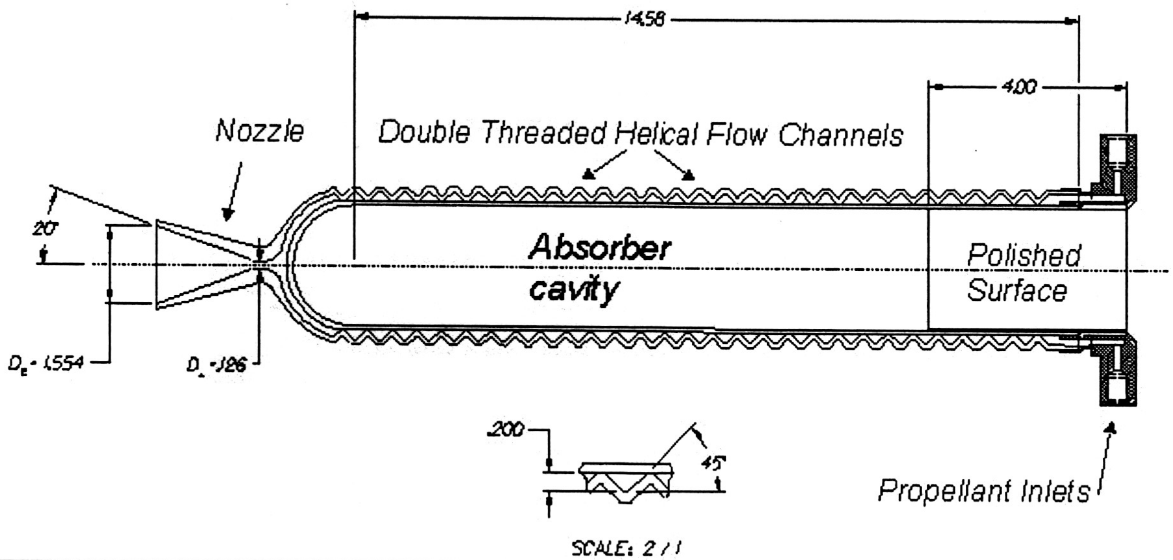
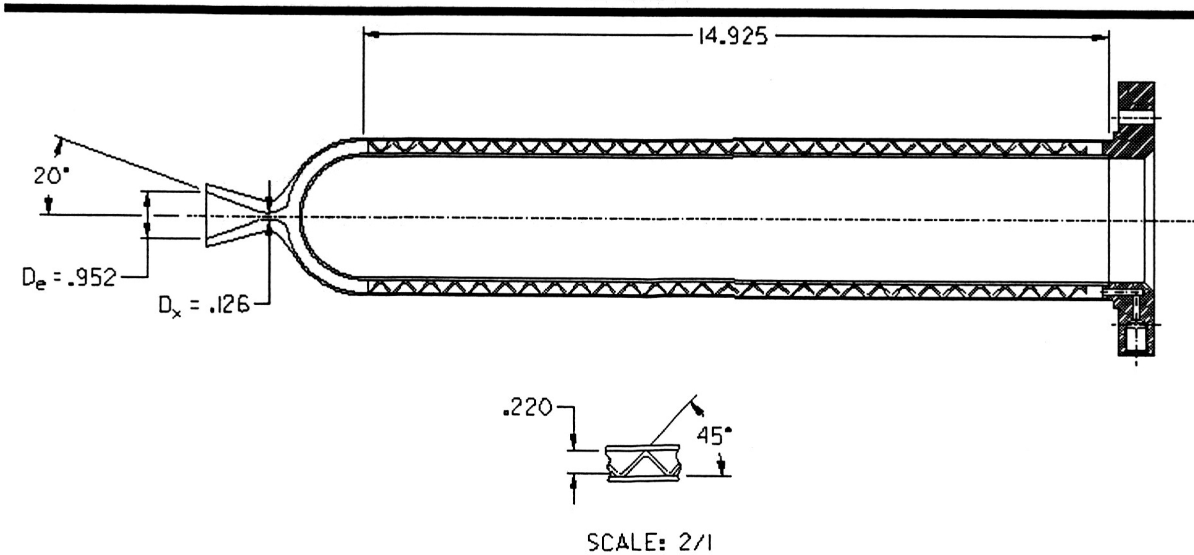


Phase I Absorber/Thruster

- Cylindrical with large L/D ratio
- Conical nozzle
- Double threaded helical flow channels

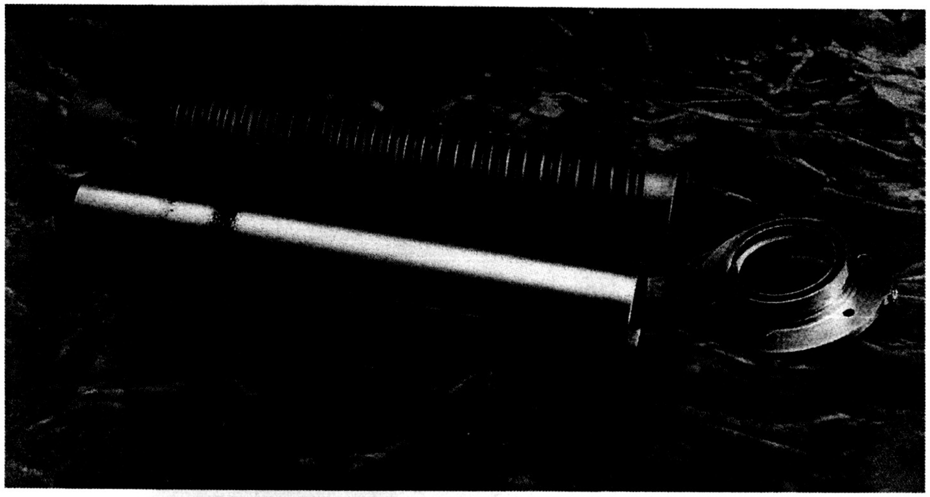


Phase II Absorber/Thruster

- Cylindrical with large L/D ratio
- Conical nozzle
- Double threaded helical flow channels,inner/outer to reduce pressure loss, increase thrust, and more surface area for heat transfer

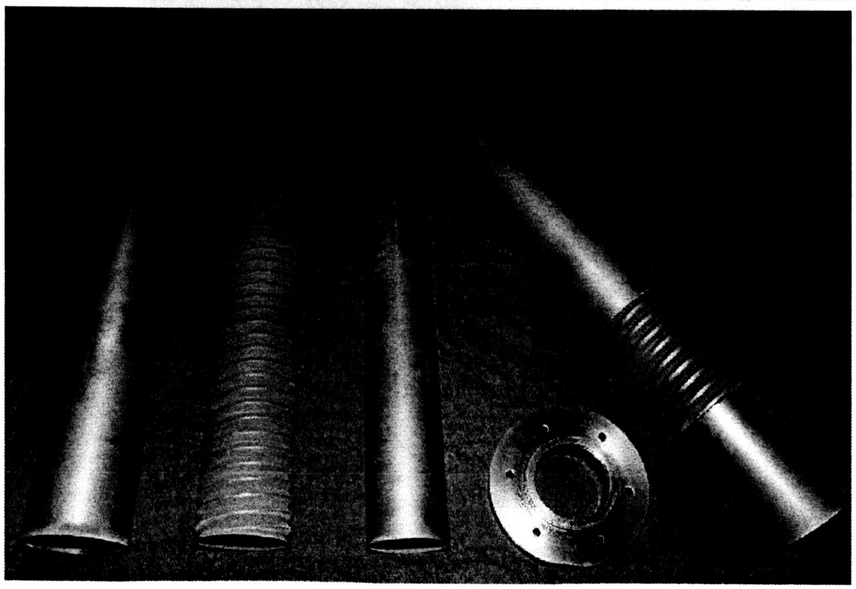
DIRECT GAIN ENGINE FABRICATION

Propulsion Research Center



Phase I Absorber/Thruster

- 100% Tungsten-Vacuum Plasma Sprayed
- Nickel Faceplate brazed



Phase II Absorber/Thruster

- 75%Tungsten/25%Rhenium Vacuum Plasma Sprayed
- 50%Rhenium/50%Molybdenum Faceplate
- Electron beam welded

SOLAR THERMAL PROPULSION DIRECT GAIN COMPONENTS

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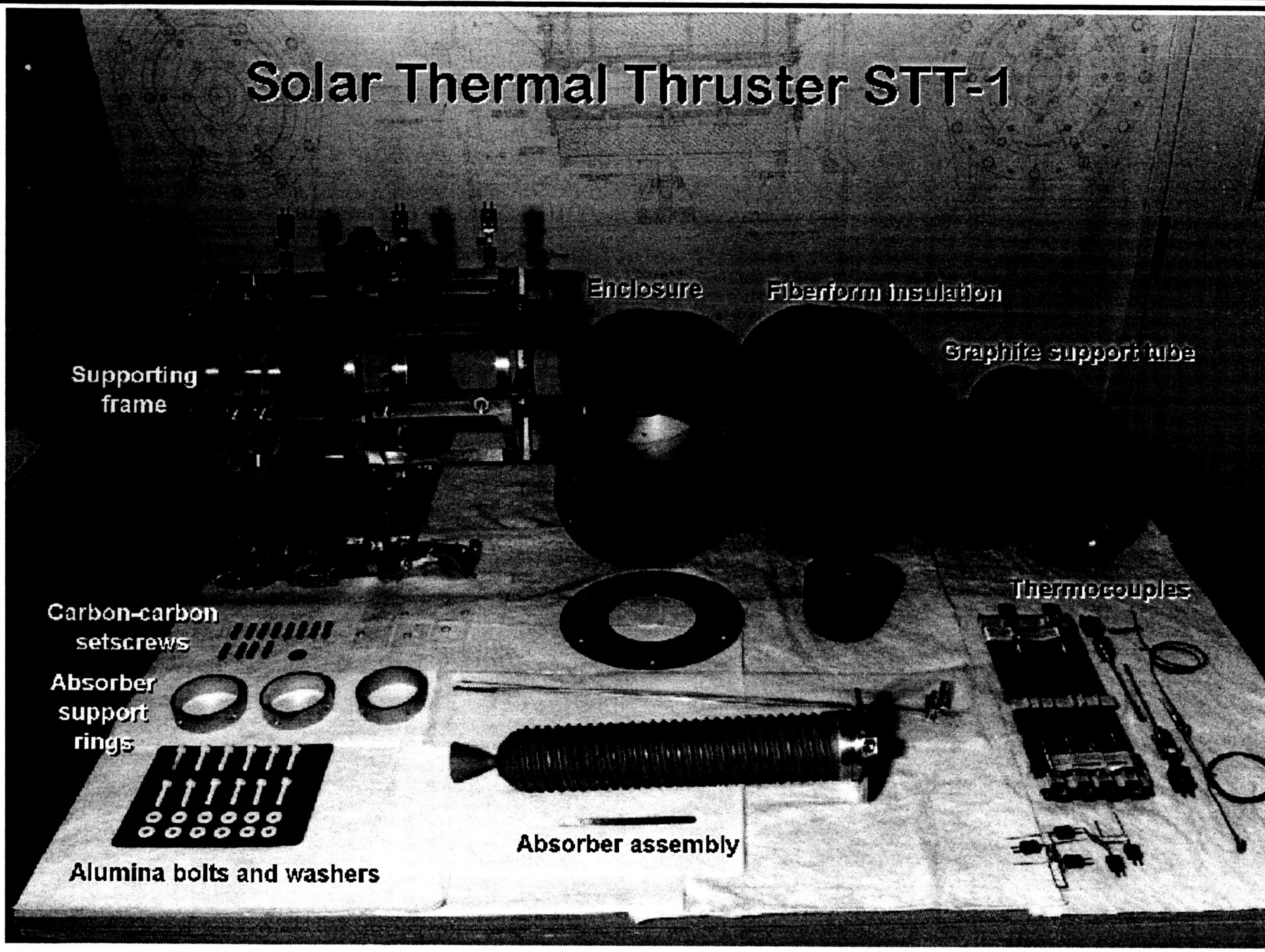
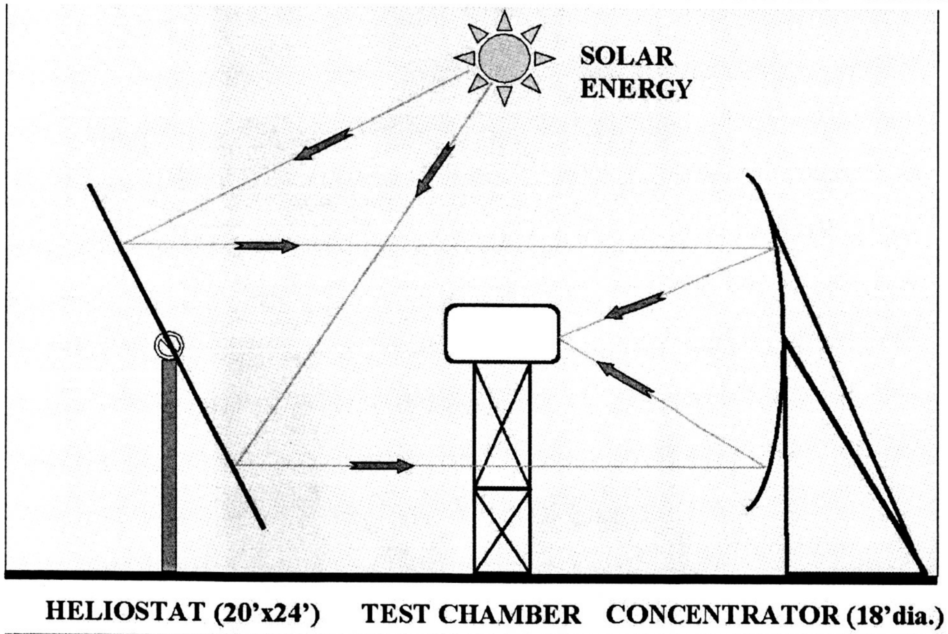
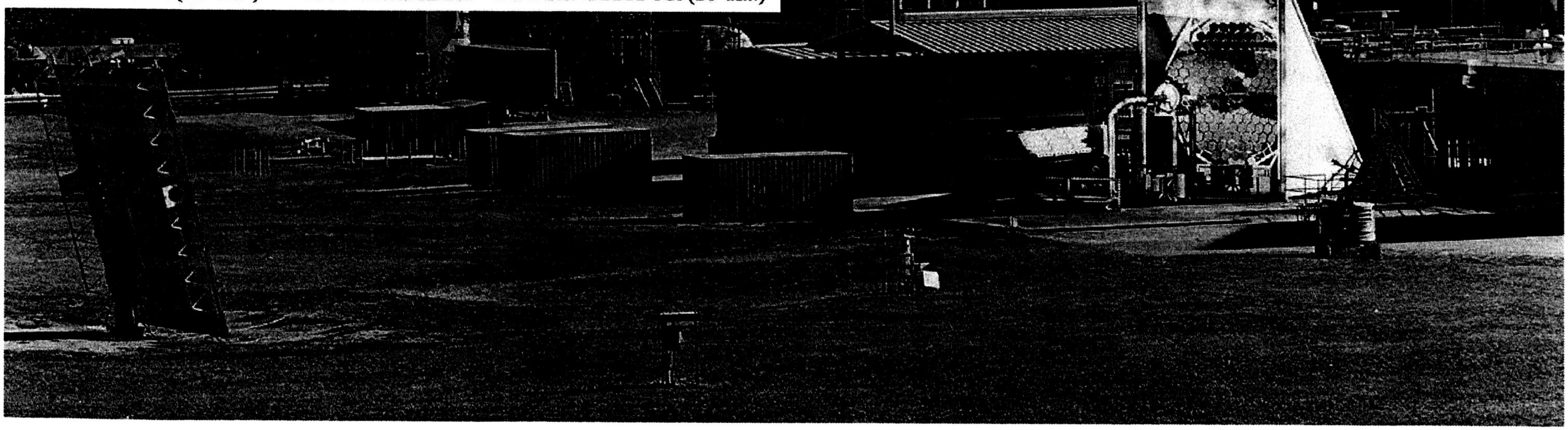


SOLAR THERMAL TEST FACILITY

Propulsion Research Center

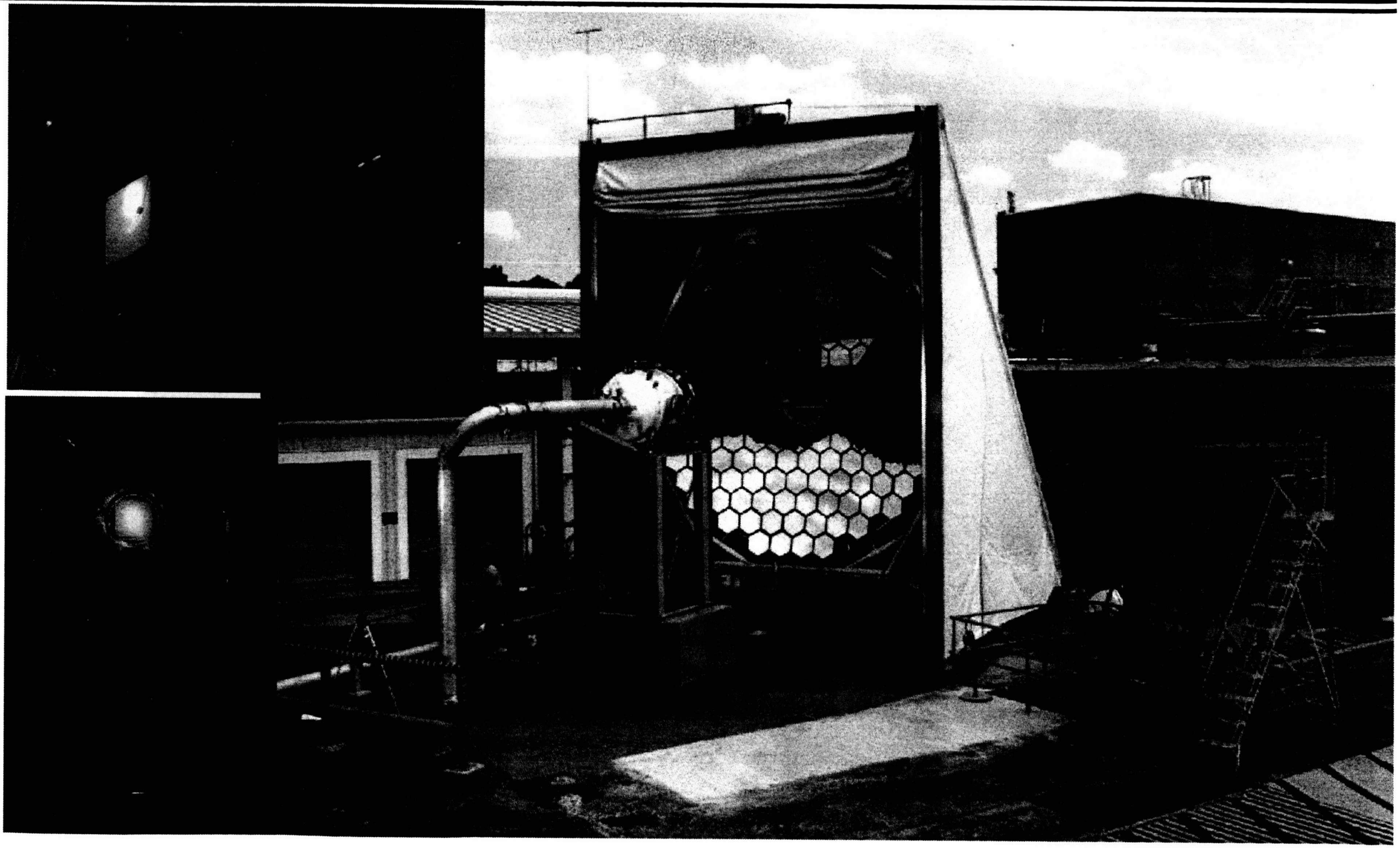


- •10 kW focused solar energy, 11cm dia.
- •91.5cm dia. X 123cm L vacuum test chamber
- •Hot hydrogen open cycle test flow
- •4 hour operating window



SOLAR THERMAL TEST FACILITY

Propulsion Research Center



CHECKOUT RESULTS

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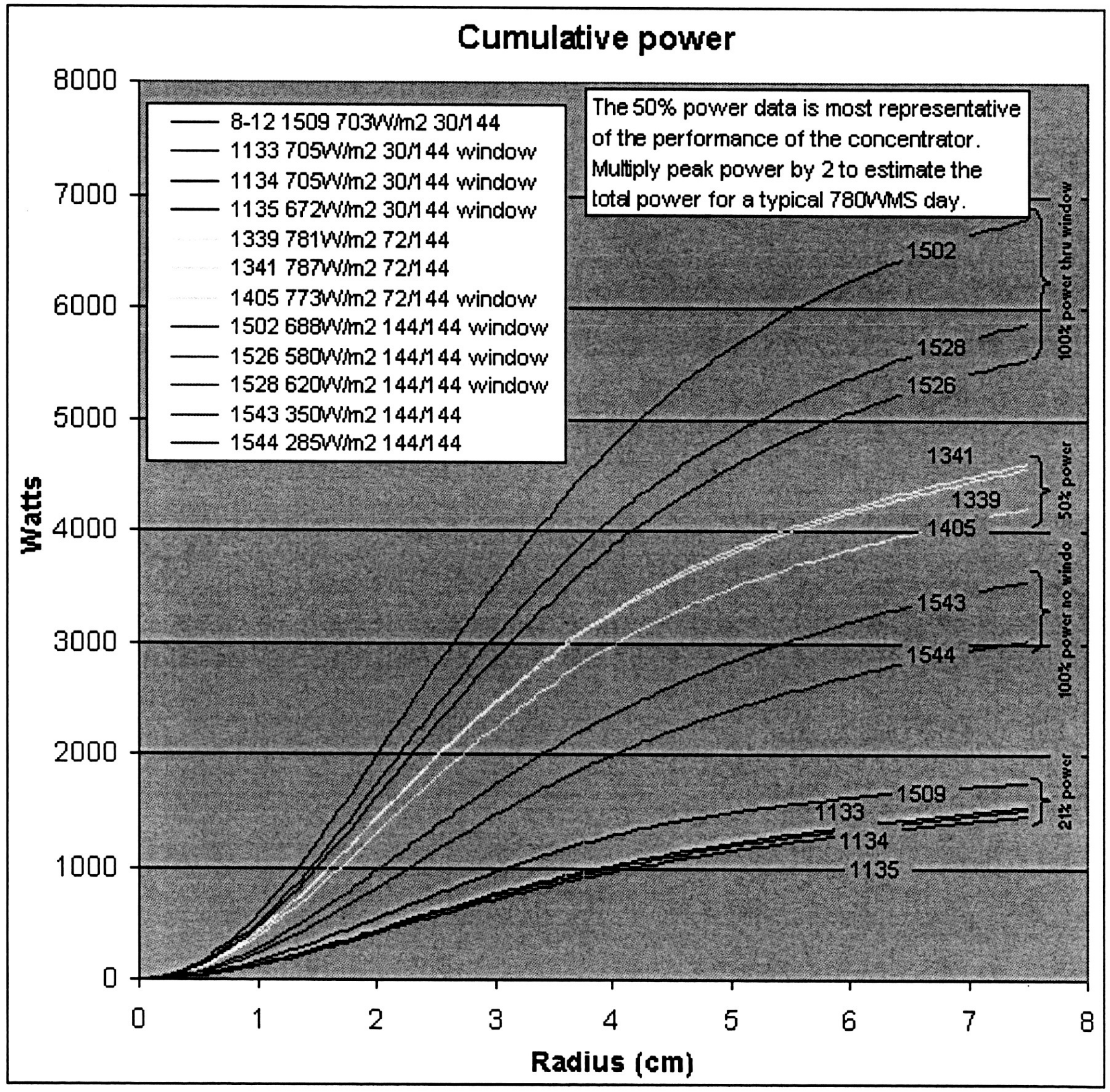
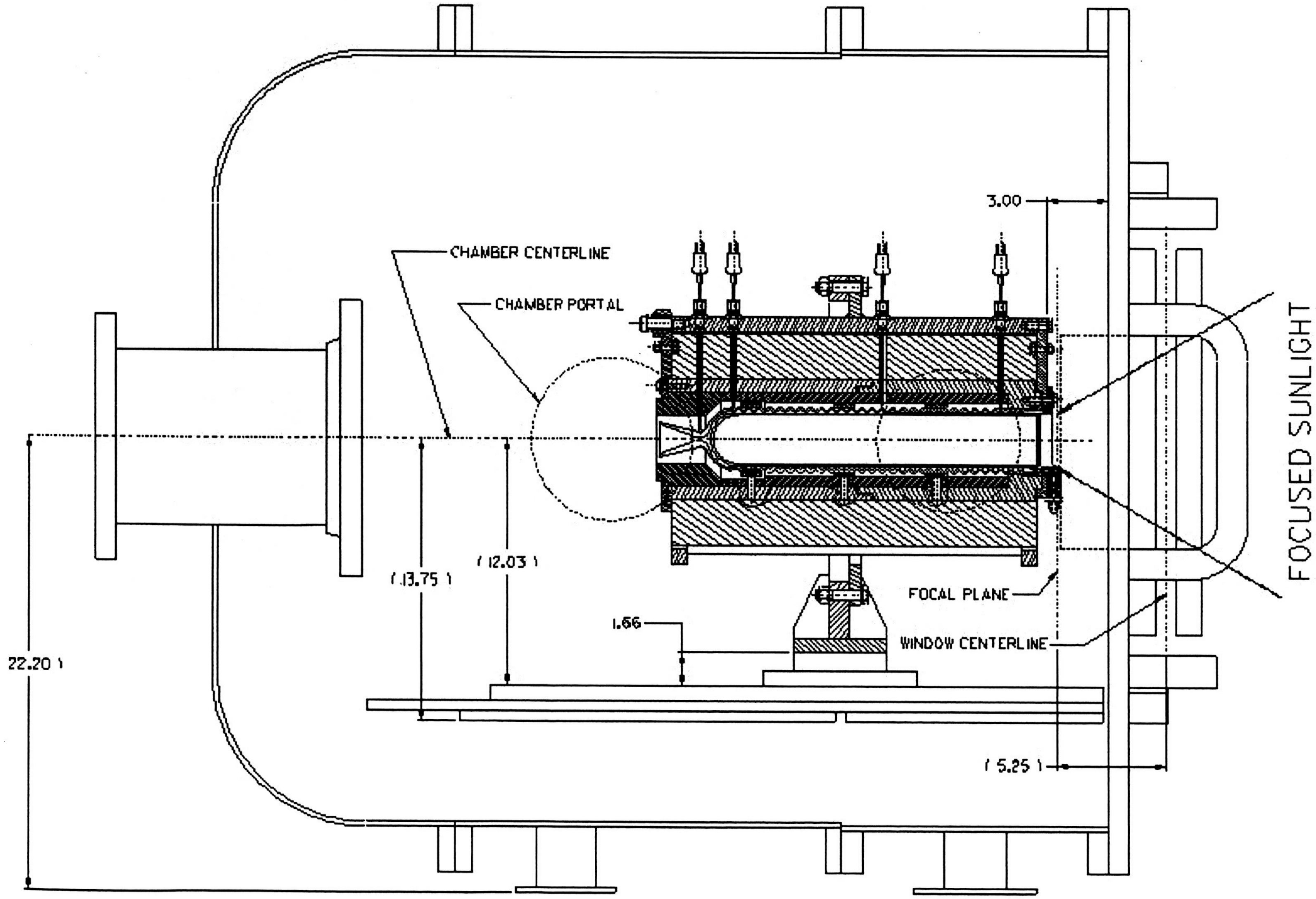
- Huntsville has 1000 W/m2 on clear sky days in the fall and spring.
- About 10 kW is focused inside a 11cm diameter focal point.



SRS and AFRL assisted with these checkouts

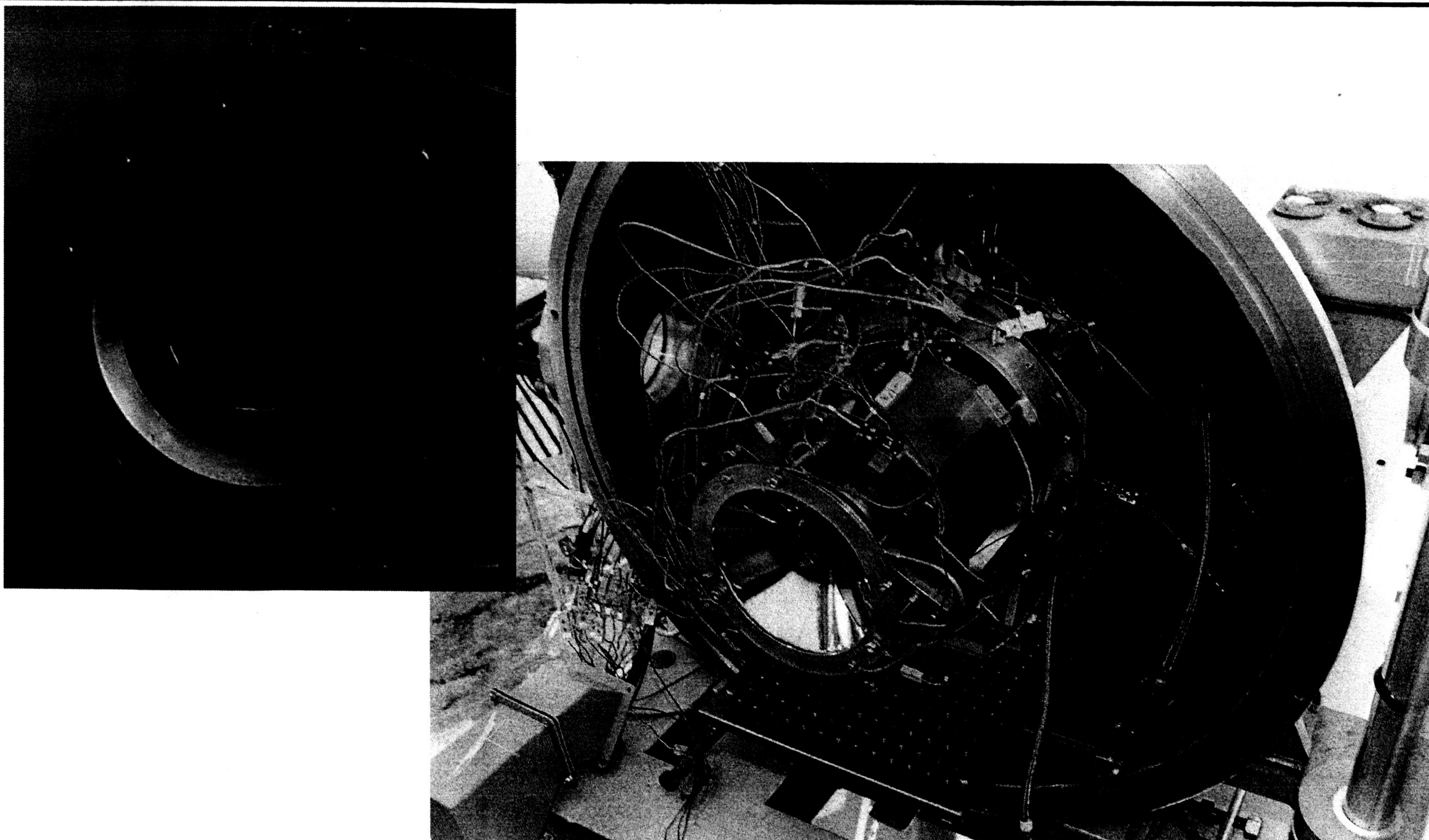
ENGINE POSITION INSIDE TEST CHAMBER

Propulsion Research Center



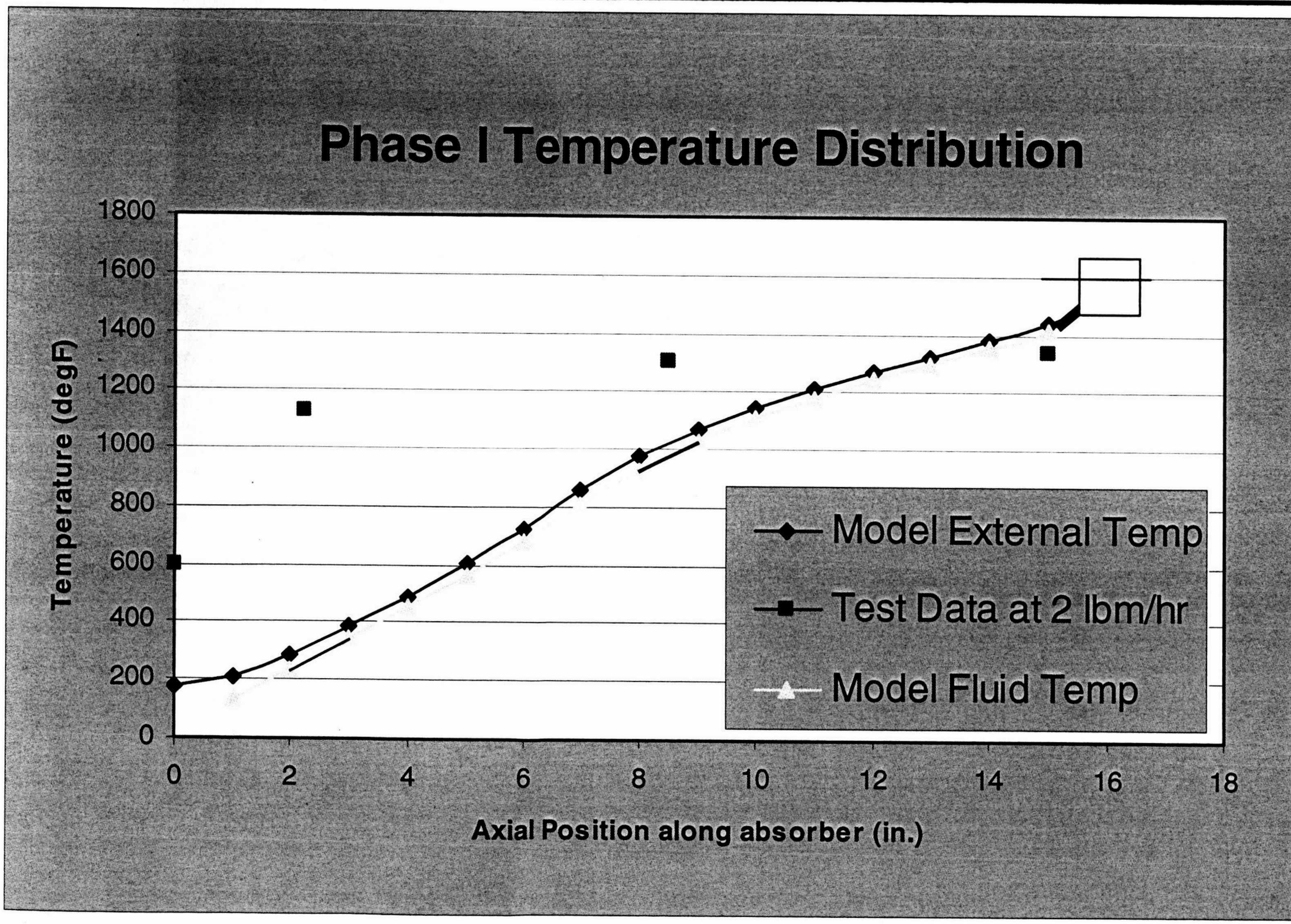
ENGINE POSITION INSIDE TEST CHAMBER

Propulsion Research Center



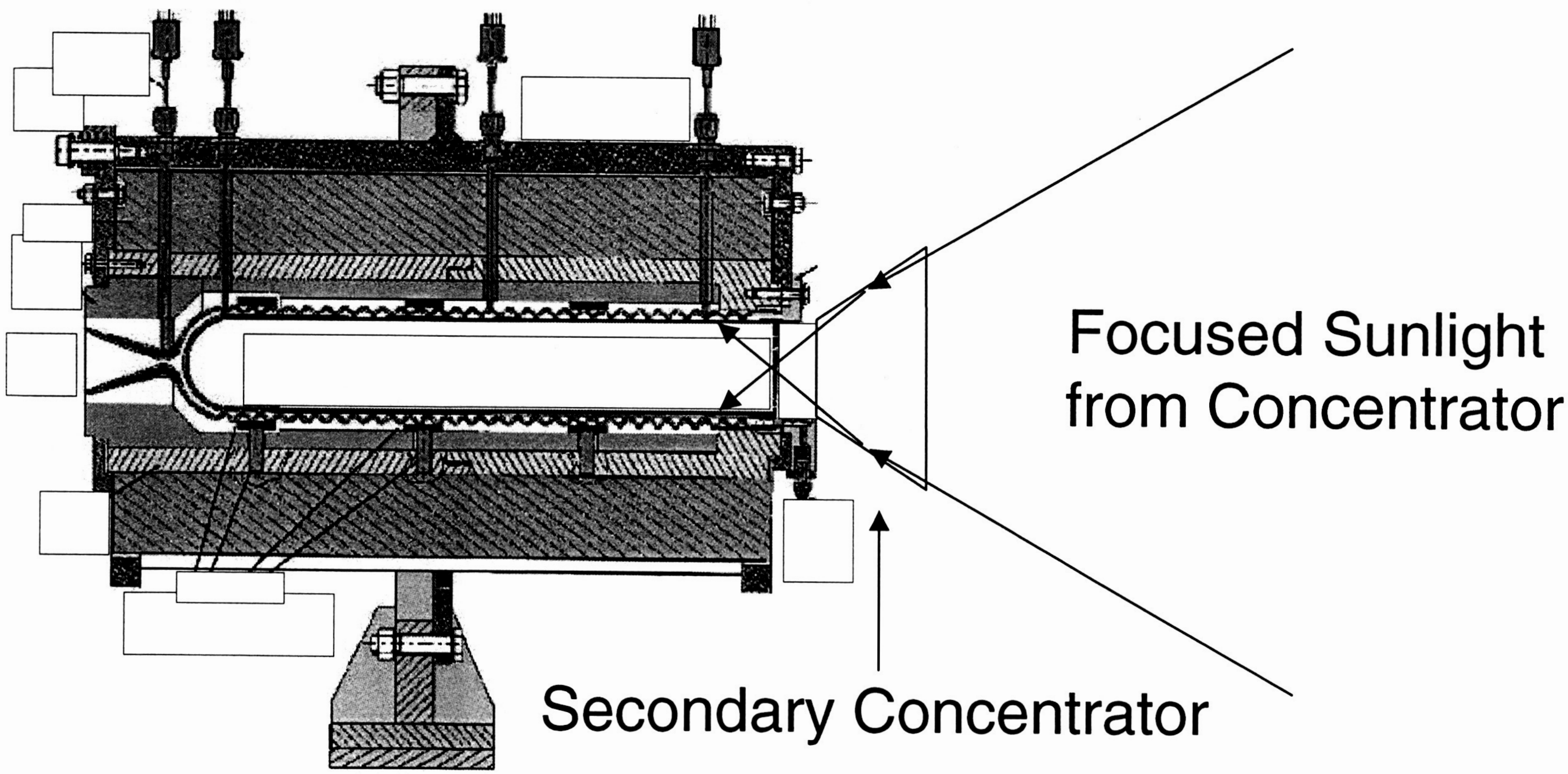
STP TEST RESULTS

Propulsion Research Center



4kW solar input to absorber cavity

SECONDARY CONCENTRATOR



Currently, in the process of adding a secondary concentrator to allow more focused energy inside of absorber cavity for higher temperatures

FY03 OBJECTIVES

Propulsion Research Center

- Reactivate MSFC Solar Test Facility with mirror protection

- Design/Fabricate a universal secondary concentrator for the Solar Test Facility to accommodate a range of STP engines

- Test 3 different types of in-house engine designs for a goal performance of 860 second specific impulse
    - 100% Rhenium
    - 75% Tungsten/25%Rhenium
    - 100% Tungsten

- Work other joint activities with outside partners

OTHER JOINT ACTIVITIES

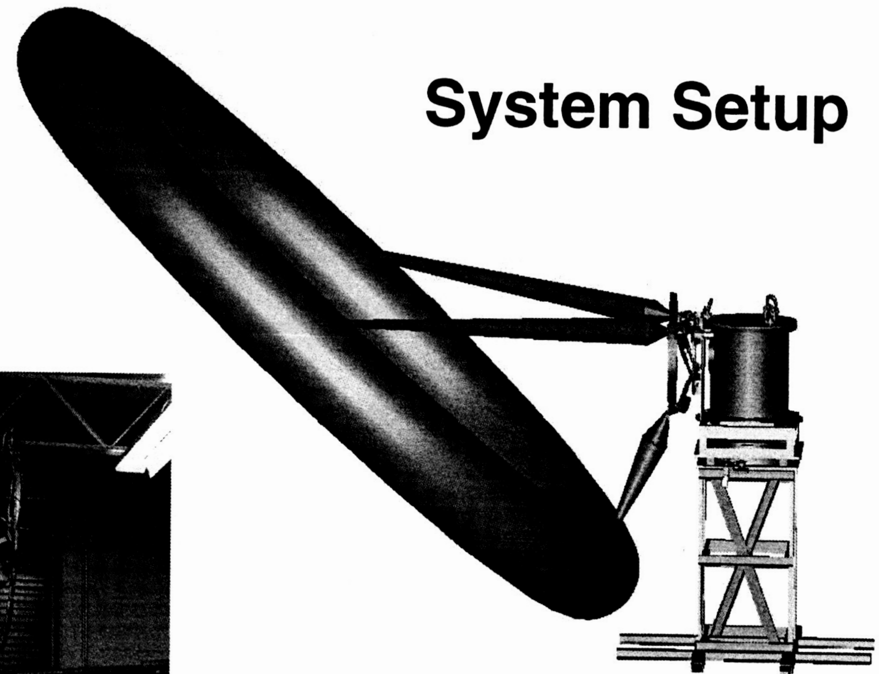
- United Applied Technologies, Auburn University Space research Institute, and General Atomics have been awarded a Phase II SBIR.
  - Using the MSFC solar facility to test a 10kW solar thermionic diode space power system with 20% efficiency goal

- Space Act Agreement in process with Thiokol, SRS, and Air Force to ground test a 4m x 6m inflatable concentrator and pointing control system at MSFC.

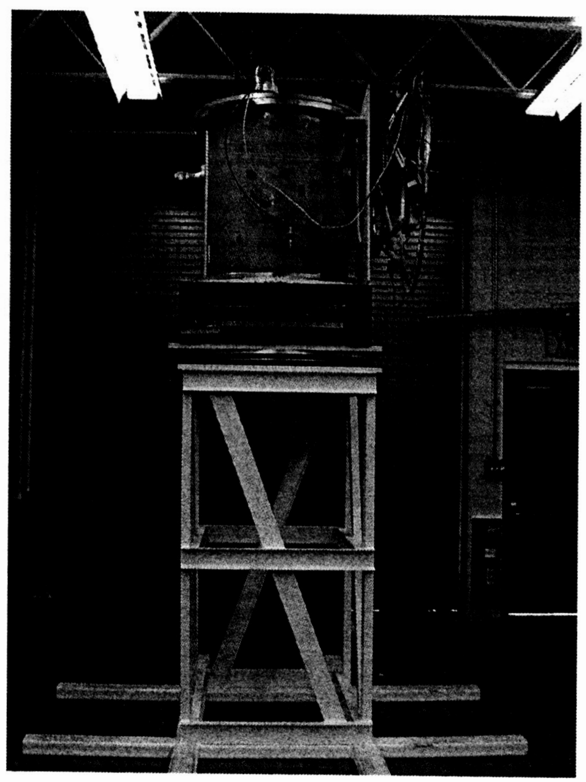
STP GROUND DEMONSTRATION

Propulsion Research Center

System Setup



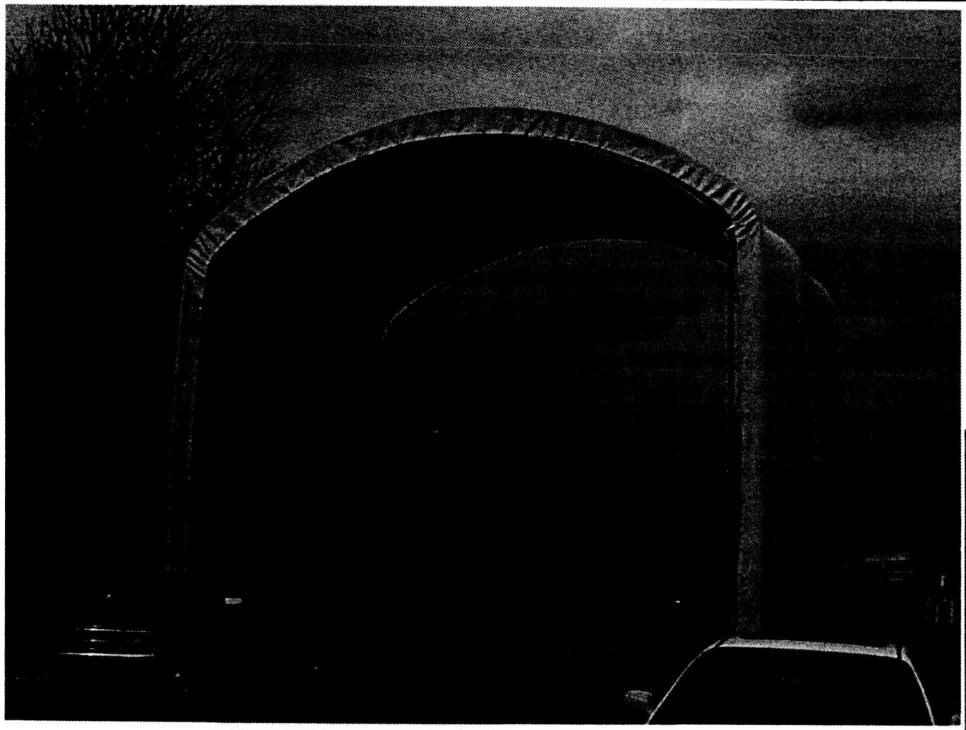
4m x 6m Inflatable Solar Concentrator



Vacuum Chamber for Solar Thermal Thruster

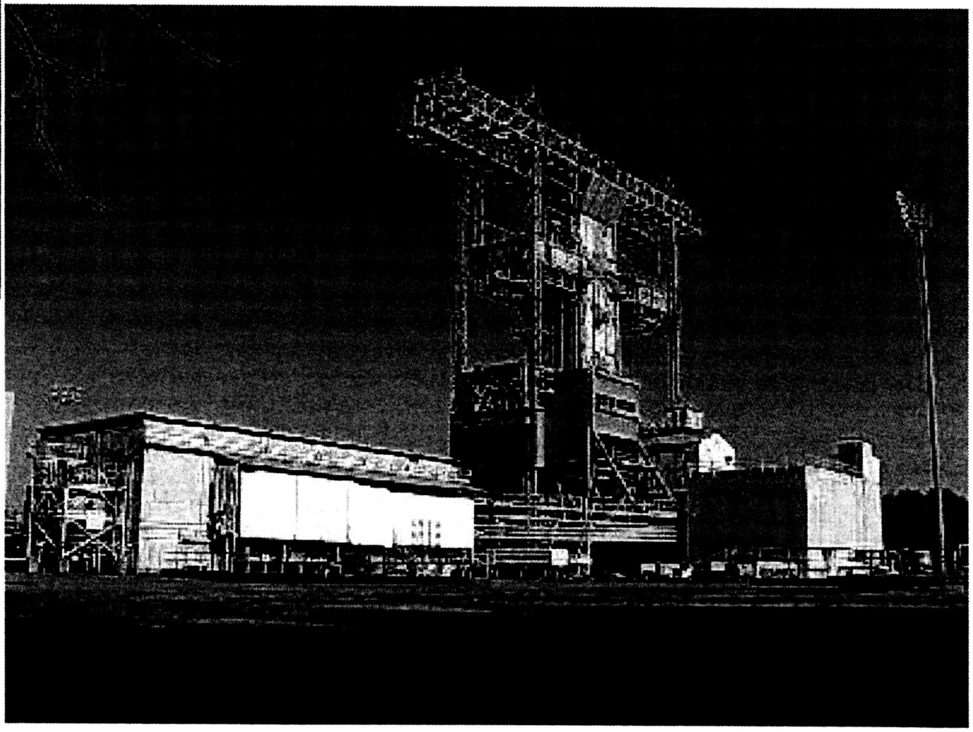
STP GROUND DEMONSTRATION

Propulsion Research Center



Test Stand 4572 in ETA location for ground demonstration

Tent from Army being modified to 32' length with closed ends



FUTURE PLANS

Propulsion Research Center

- Based on FY03 engine test results, design a new STP engine made of ceramic material to withstand high temperatures 3000K to 3400K, and increase Isp to above 1000 seconds

- Continue to work joint STP partnerships to help raise the technology readiness level for commercial use